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The heavy rainfalls of 22–23 September 1992

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Summary

The extent and limits of the heavy rainfalls occurring during 22–23 September 1992 are investigated. The last comparable historical precedent was found to have been 14–15 September 1968 in south-eastern England.

1. Introduction

After residual outbreaks of thundery rain had died out over East Anglia by mid-morning on 22 September 1992, much of the south-eastern half of England remained overcast and misty in potentially very unstable warm sector conditions. Slow-moving heavy showers and thunderstorms began to develop during the early afternoon, and a wet night ahead was forecast for the South-East. In this account all times are UTC.

2. Synoptic developments

A double cold-frontal structure was being followed on 22 September 1992, and this was moving steadily eastwards over northern England (Fig. 1). The second cold front was being disrupted by orography further south, particularly over Wales. Dashed lines indicate where minor troughs had formed, or sea-breezes were initiating convergence lines.

Although indistinct in the south, analysis of the eastern frontal system could be arbitrarily drawn (in Figs 1(a) and 1(b)) between the 15 °C dew-point temperatures on the surface in the warm sector, and the slightly cooler, less-oppressive air to the west and south. The instability of the air over the south of the United Kingdom is shown in Fig. 2(a). At this time the centre of low pressure was ill-defined at about 1006 hPa. It deepened slowly at a modest 1 hPa per 3 hours during the evening and overnight as an upper cut-off low approached from the south-west (Fig. 2(b)).

The surface depression became double-centred near The Wash from 0100 on the 23rd, with a triple-point depression moving northwards, while the other centre prolonged in the rain as it drifted over East Anglia (Figs 1(d)–1(f)). By 0600 the 500 hPa low was also over East Anglia and in the process of becoming complex.

The onset of a moderate north-north-easterly surface wind at Wittering and Bedford by 2100 on the 22nd suggests that development of the (thundery) back-bent occlusion could first be included in Fig. 1(c). Thundery activity associated with this feature was last reported as far south-west as south Oxfordshire between 2300 and midnight, with radar imagery revealing that, thereafter, heavy rain marked its passage south-eastwards to the Sussex coast by 0600 on the 23rd.

3. Radar study

Fig. 3 is a three-hourly sequence of UK Weather Radar Network 'modified composite pictures' produced by FRONTIERS, which may be compared with the surface synoptic charts of Fig. 1. Coloured pixels represent precipitation intensities averaged over 5 km × 5 km squares, as shown in the caption.

At first, there was little evidence of a definite frontal structure, the precipitation pattern (in Fig. 3(a)) showing convective development of heavy showers and thunderstorms as the afternoon progressed. In Fig. 1(a), the development of a mesoscale warm-frontal wave was

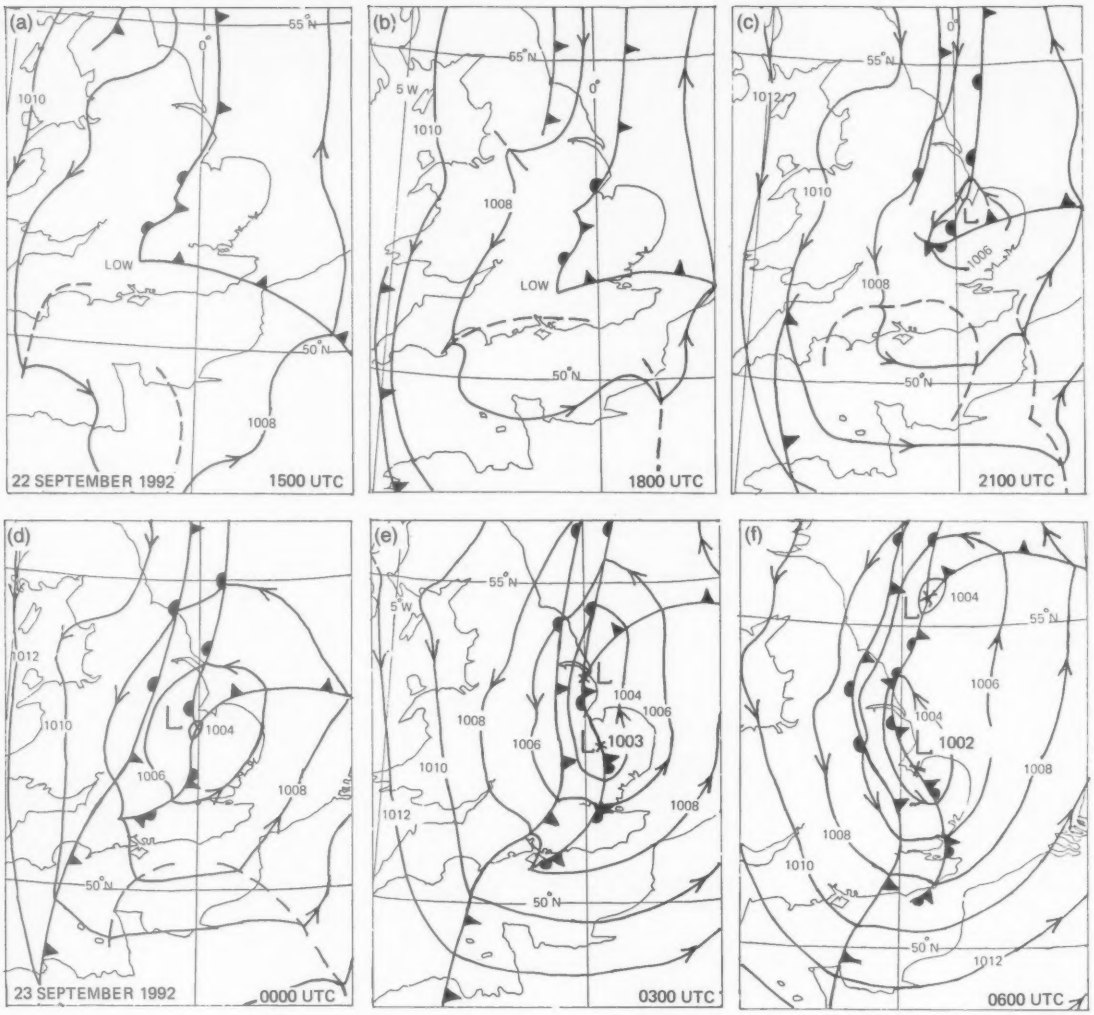

Figure 1. Surface synoptic charts at 3-hour intervals from 1500 on the 22nd to 0600 on 23 September 1992.

indicated (by surface wind and temperature observations) just to the north of Bedford, where the very heavy rain reported at DRA Bedford and Riseley was probably falling from slow moving embedded cumulonimbus. Fig. 3(b) indicates that precipitation areas had generally increased in size and intensity by 1800 on the 22nd, when returns from the warm frontal ripple had become more marked and intense (a remarkable fall of 54mm was recorded in two hours between 1700 and 1900 at Rutland Water).

Where a south-westerly sea-breeze opposed the northerly gradient wind near the south-east coast of Devon, a notable convergence line formed and, by 1800, had lengthened considerably near the south coast (Figs 3(a) and 3(b)). Heavy showers and thunderstorms developed in a slow-moving band along this line through southern Somerset (where Yeovilton had a noteworthy fall of 42.2 mm in the two hours between 1600 and 1800) and Dorset; lighter showers formed as far east as Sussex.

Fig. 3(c) shows the general expansion and intensification of precipitation areas continuing at 2100 over most counties south-east of a line from the Humber to the Severn. The warm-frontal wave was being absorbed by the deepening surface depression at this time, but an area of very heavy rain which had formed in its vicinity was affecting a considerable area between Grantham and Peterborough. During the evening of the 22nd noteworthy falls were recorded at the National Rivers Authority (NRA) gauges at Manthorpe (56 mm in 3 hours of which 37 mm fell between 1800 and 2000) and Chesterton Reservoir (31 mm between 2000 and 2200).

The merger of precipitation lines and areas continued during the late evening, and by midnight the transformation from a convective to a frontal precipitation pattern

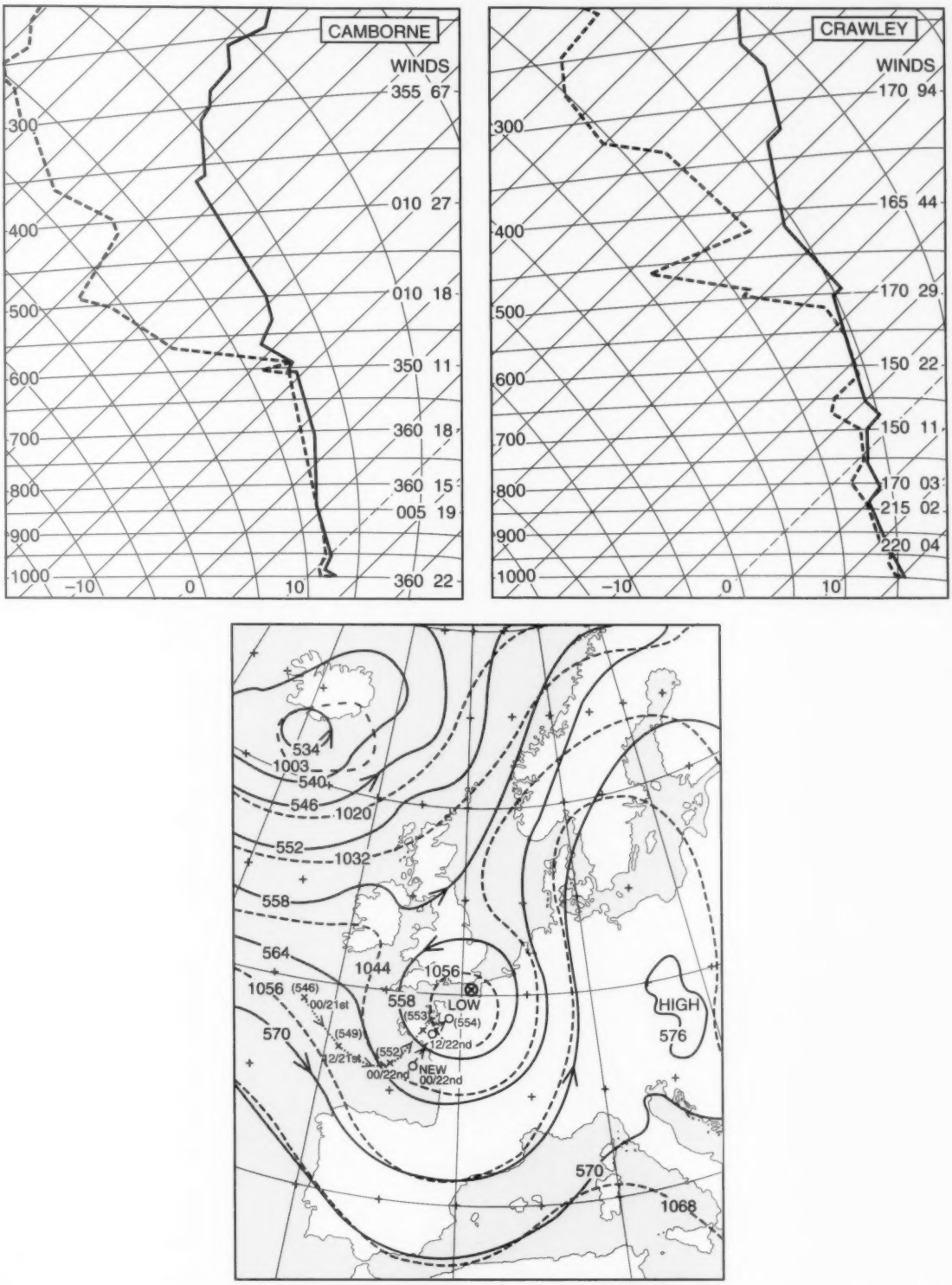

Figure 2. Tephigrams showing the unstable air over southern England at 1200 on 22 September 1992, and upper-air charts for midnight on 22/23 September 1992: 500 hPa streamlines in solid lines, 250 hPa in dashed lines (heights in decametres). 12-hour continuity of centres given by lines of dots (crosses represent the 500 hPa centre continuity).

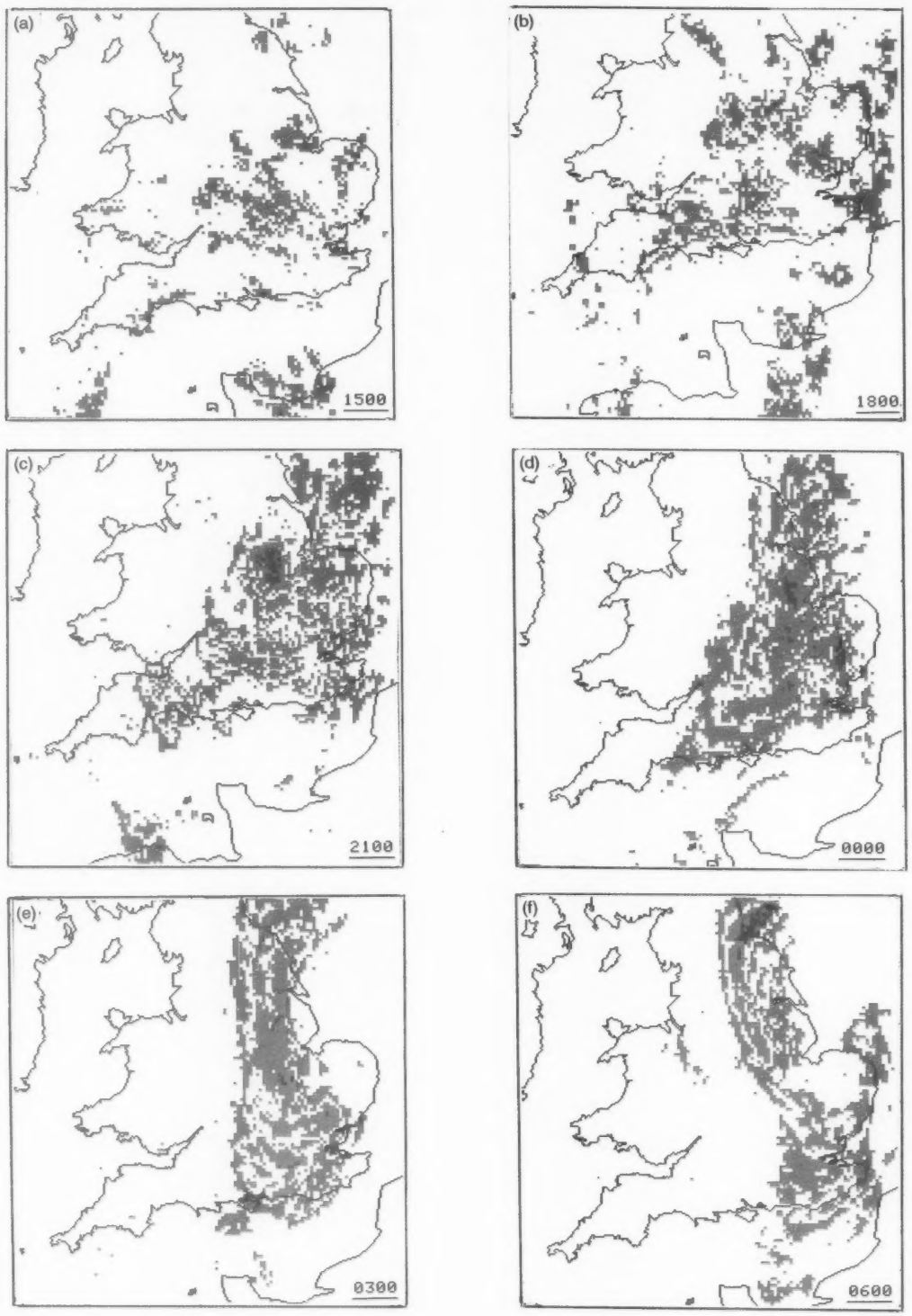

Figure 3. UK weather radar network 'modified composite' precipitation intensity data at 3-hour intervals comparable to Fig. 1. Colours represent intensities: green, less than 2 mm h^{-1}; yellow, 2–4 mm h^{-1}; red, 4–8 mm h^{-1}; pink, 8–16 mm h^{-1}; purple, 16–32 mm h^{-1}; cyan, 32–64 mm h^{-1} black, over 64 mm h^{-1}. Pixels represent 5 km × 5 km squares.

was more or less complete. Fig. 1(d) suggests that the second front had become an integral feature at the western edge of the precipitation, which was returning westwards over Humberside.

Nine main synoptic stations* in the rain area were reporting continuous heavy rain at 0200. By 0300 on the 23rd (Fig. 3(e)) a 'dry slot' appears over the Ely area of Cambridgeshire, and this is echoed in the 24-hour total rainfall distribution chart (Fig. 4), suggesting that the heavy rain further west and south over the county had remained slow moving for several hours.

The depressions were beginning to transfer northwards by 0600 (Figs 1(f) and 3(f)) with rain becoming concentrated on the leading front (i.e, warm front in the north, occlusion in the south), with heaviest rainfall over Teesside. Precipitation was at last beginning to die out over Peterborough and Cambridgeshire, although drizzle continued there for several hours, falling from low cloud below the radar scan.

* Wittering, Bedford, Wyton, Coningsby, Benson, Stansted, Odiham, Heathrow and London Weather Centre.

4. Rainfall analysis and flooding

Fig. 4 gives the 24-hour rainfall distribution chart for 22–23 September 1992, with gauge readings (standardized where possible) at 0900 on the 23rd. In many places, a general background overnight fall of 50 mm was added to the 25–50 mm which had fallen in showers or thunderstorms on the 22nd, giving the wettest 24 hours in some stations' history.

Probably not since the 14–15 September 1968 episode has such a large area of heavy rainfall occurred in September over the south-eastern half of England. Then, around the Thames Estuary, 125 mm fell in 24 hours over north-west Kent, with 200 mm in 48 hours over extreme southern Essex. Flooding was rather more widespread on that occasion, especially in Surrey (see Salter

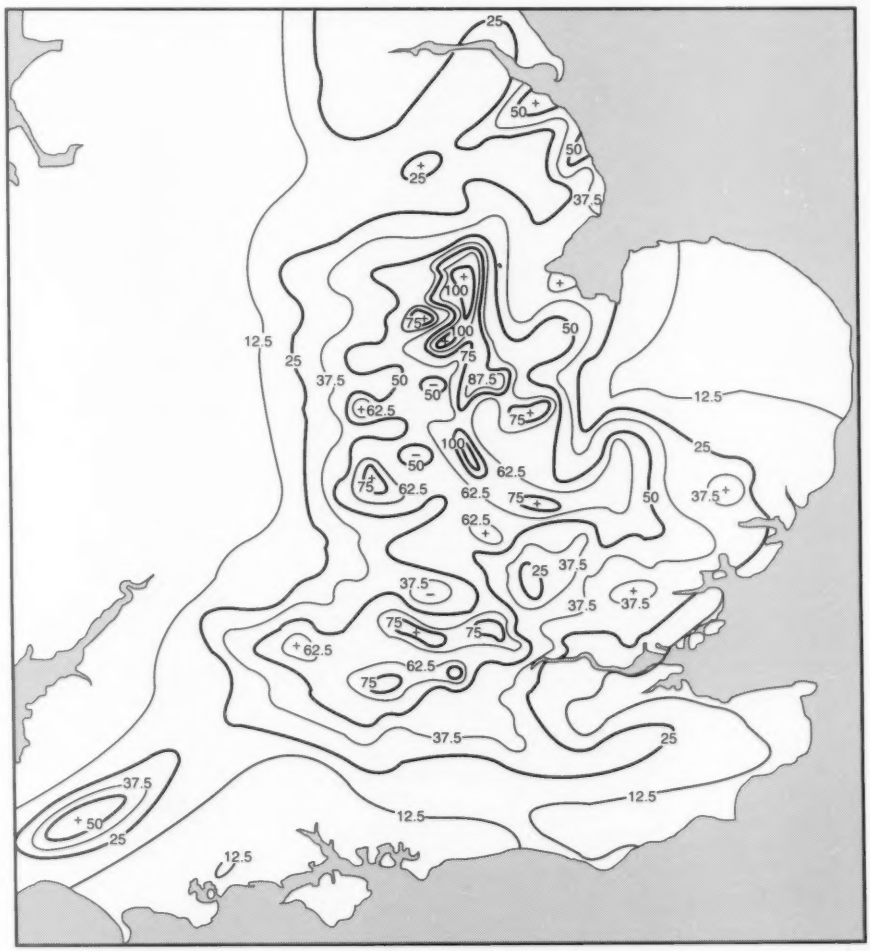

Figure 4. Twenty-four-hour rainfall totals read at 0900 on 23 September 1992. Isohyets; thick lines at 25 mm intervals; thin lines at intermediate 12.5 mm intervals.

and Richards (1974)). Other recent notable falls of 100 mm or more have occurred in recent years in connection with summertime thundery situations. Firstly, an area from Raunds (Northamptonshire) to Fosdyke (Lincolnshire) was affected on 10 July 1968 (Salter 1969) and a small area of Northamptonshire was cited again as receiving 100 mm on 26 July 1980 (by Waterfall (1982)). Flooding associated with the 'Hampstead Storm' of 14 August 1975 in parts of north-west London (described in Keers and Wescott (1976)) was equally if not more damaging than that which affected the Edgware area on 22–23 September 1992.

The Times (of 24 September 1992) carried pictures of people in Edgware (where the Silkstream had overflowed) being rowed to safety in boats over streets flooded 'with up to four feet of water'. The report continued that 'Edgware General Hospital was flooded with two inches of water, and the casualty department had to be closed. Firefighters tried throughout the night to stem the flood which swept through four wards'. The NRA's Harrow Weald gauge recorded 80.2 mm — a listing of fifteen gauges with greater 24-hour readings is given in Table I, as are other reports of over 70 mm.

Because of long-term ground moisture deficits, rainfall totals in excess of 2 inches (128 locations reported falls of 50.8 mm or more over a considerable area shown in Fig. 4) appear to have been needed to end the drought. Certainly, reservoirs and rivers which had either dried up or had been running in a depleted state for many months were now, at least, partially filled. A typical 'periodic' chalk downland stream, the River Pang at Frilsham, was found to have 'two feet of murky water' in it on the 23 September, according to Peter Bloodworth in *Newbury Weekly News* of Thursday the 24th. However, 70–75 mm appears to have been the real threshold for more serious or longer-term flooding to have occurred near overburdened streams and rivers where, in western Fenland and other clay vale areas, flooding lasted several days in places. The River Great Ouse flood levels had reached 40 cm on the 23rd but were still running near

Table I. Rainfall totals in excess of 70 mm for the 24 hours ending 0900 on 23 September 1992

	Station	Total (mm)	Nat Grid Ref.	Met. Office ref. or other source
1.	Lodge Farm, Walcot, Nr Sleaford, Lincs	113.3	TF 060351	147674
2.	Rutland Water	109.0	SK 946081	NRA, Lincoln
3.	Grimsthorpe, Lincs	106.1	TF 047231	NRA, Lincoln
4.	Riseley, Beds	106.0	TL 042628	COL
5.	Old Somerby, Grantham, Lincs	99.0	SK 964339	154818
6.	Yaxley, Nr Peterborough	99.0	TL 196934	196776
7.	Manthorpe, Lincs	96.5	TF 067164	NRA, Lincoln
8.	Warmington, Nr Peterborough	92.4	TL 082913	163388
9.	Carlby, Nr Stamford, Lincs	91.6	TF 049142	156000
10.	Culverthorpe, Nr Grantham, Lincs	89.6	TF 025402	148248
11.	DRA Bedford (Thurleigh)	89.0	TL 037587	The Met. Office
12.	Corby Glen, Lincs	85.0	SK 992246	NRA, Lincoln
13.	Chesterton Reservoir, Nr Peterborough	84.0	TL 128946	NRA, Lincoln
14.	Litchborough St Martin, Northants	83.6	SP 633542	158714
15.	Radnage, Bucks	83.3	SU 791952	274267
16.	Harrow Weald (Cemetery), Gtr London	80.2	TQ 153920	NRA, Reading
17.	Warboys, Cambs	79.9	TL 303801	196001
18.	Rickmansworth, Herts	79.3	TQ 052948	COL
19.	RAF Wittering, Nr Stamford	79.2	TF 039031	The Met. Office
20.	Castle Bytham, Grantham	78.6	SK 985174	155271
21.	Oundle STW, Northants	78.5	TL 038897	NRA, Lincoln
22.	Royston, Herts	78.1	TL 346402	182578
23.	Lodge Cottage, Pilton, Peterborough	77.6	TL 014849	162865
24.	University of Reading, Berks	76.3	SU 743717	University of Reading
25.	Bourne End STW, Bucks	76.2	SU 892881	274134
26.	Towcester STW, Northants	76.0	SP 695487	170809
27.	Northwood, Gtr London	75.1	TQ 094916	COL
28.	Windsor (Royal Gardens) Berks	74.5	SU 979754	275574
29.	London NW2	74.2	TQ 240849	COL
30.	Brook Farm, Swineshead, Beds	74.1	TL 061658	177833
31.	Ufford, Nr Stamford, Lincs	73.1	TF 094044	153908
32.	Saltersford Weir, Nr Grantham, Lincs	73.0	SK 926335	NRA, Lincoln
33.	Birkholme, Lincs	72.8	SK 969235	155011
34.	Caversham, Berks	72.4	SU 720740	265922
35.	Great Stukeley, Huntingdon	70.9	TL 217745	179264
36.	Gunthorpe Hall, Nr Oakham	70.4	SK 869057	153244

STW = Sewage Treatment Works
COL = Climatological Observers' Link

Table II. Bilham (1935) Classifiable 'remarkable' and 'noteworthy' rainfalls on 22 September 1992

A. Remarkable fall:			
1.	Rutland Water. (SK 946081)	54 mm in 120 min (1700–1859; 31.5 mm in first hour).	NRA, Lincoln
B. Noteworthy falls:			
1.	DRA Bedford* (TL 037587)	27 mm in 57 min (1453–1550)	The Met. Office
2.	Litchborough STW (SP 624551)	26 mm in 60 min (1600–1659)	NRA, Lincoln
3.	Yeovilton, Somerset	42.2 mm in 120 min (1600–1800)	The Met. Office
4.	Manthorpe, Lincs (TF 067164)	56 mm in 180 min (1800–2100) (25.0 mm, 1800–1859; 12.0 mm, 1900–1959; +16.0 mm, 2000–2059)	NRA, Lincoln
5.	Chesterton Res.(TL 128946)	31 mm in 120 min (2000–2259;	NRA, Lincoln

* See Figure 5

30 cm on the 26th. The *Rutland and Stamford Mercury* of Friday the 25th reported the B1177 Billingborough to Horbling road still 'impassible to motorists'. This is in a low-lying Fenland location just 9 kilometres from where the maximum 113.3 mm 24-hour rainfall (see Fig. 4) had occurred.

Table II lists those classifiable 'heavy falls in short periods' (Bilham 1935) that were recorded by tilting-siphon or tipping-bucket rate-of-rainfall gauges. Several have been mentioned in Section 3, but it may be added that the locations of Manthorpe and Chesterton are similar to that of Walcot, i.e. on the first rising ground immediately west of the relatively flat Fenland. This could point to orographic enhancement as being an ingredient of some particularly heavy falls in both Tables here.

In addition to the officially recognized records in Table II, there were two further reports of noteworthy falls during the afternoon storms of Tuesday the 22nd from keen volunteer Thunderstorm Census Organisation (TCO) observers. Mr R. Peverall at Stony Stratford, Bucks, measured 28 mm in 70 mins (1450–1600) during a thunderstorm. At Wappenham (Northants, NGR SP623457, 16 km away to the west-north-west) 25 mm fell in 40 mins (1450–1520) but before the thunder and lightning, which occurred from 1525–1630 with a further 8 mm of rainfall, according to local publican, Mr R.L. Mobbs. As a 'postscript', he reported that the difficulties experienced by his customers travelling by road (due to local flooding of the River Tove system) lasted for 48 hours following the heavy overnight rain of 22/23 September.

With electrical activity lasting 70 minutes at Stony Stratford and 65 minutes at Wappenham, given light to moderate south-easterly cloud-steering winds backing from SSE to ESE with time on Crawley and Hemsby by ascent, it is quite probable that the same thunderstorm was involved, albeit in a decaying state, arriving at Wappenham some 40 minutes later, after the deluge-producing cell which had developed ahead. Other TCO observers in central East Anglia reported thunderstorms moving slowly from south-east to north-west.

Fig. 5 shows three traces from tilting-siphon rate-of-rainfall recorders for the 24 hours ending 0900 on the 23rd. All three show a long period of heavy rain. The University of Reading had its wettest 24-hour period since records began in 1921. The basic design of the tilting-siphon rain recorder has not changed much since its invention by Dines (1920), who reported its 'satisfactory' use at Benson Observatory 'since January 1915'. Once correctly installed and adjusted, the only problems he encountered were foreign objects (earwigs) blocking the siphon tube, but he later found that storm debris obstructing the collecting funnel also produced untrustworthy rates of rainfall on the records. Over the years, Met. Office development has improved the speed of the siphoning process by introducing a double siphon tube, but apart from refining the collection method somewhat, the essential mechanism has remained largely unaltered, a testament to its sound original conception.

Usually, between 0.2 and 0.5 mm are lost during the mechanical siphoning process, depending on the intensity of the rainfall. The instrument at Wyton needs a slight adjustment to correct its zero setting, but otherwise the record is a good one. Unfortunately, there is no record at all from Wittering where adequate drainage was a problem, the instrument siphoning only once before being flooded out. Hourly records show heaviest rain occurring at Wittering between 2000 and 2200 on the 22nd (when 23.5 mm fell) and again between 0100 and 0200 on the 23rd (with a further 12.3 mm).

Fig. 5 gives a clear picture of the noteworthy fall at Bedford, showing the initial torrential rainfall tailing off in intensity with time from its onset at 1453 to cessation at 1550. The trace appears to be typical of convective rainfall coming from a cumulonimbus cloud. Thunder was not observed at Bedford until mid-evening, however, reports from adjacent counties indicate that showers and thunderstorms were occurring by mid afternoon.

5. Conclusions

The heavy rainfall of 22–23 September 1992 will probably be most memorable for 'ending the drought' over a wide area of the south-eastern counties of

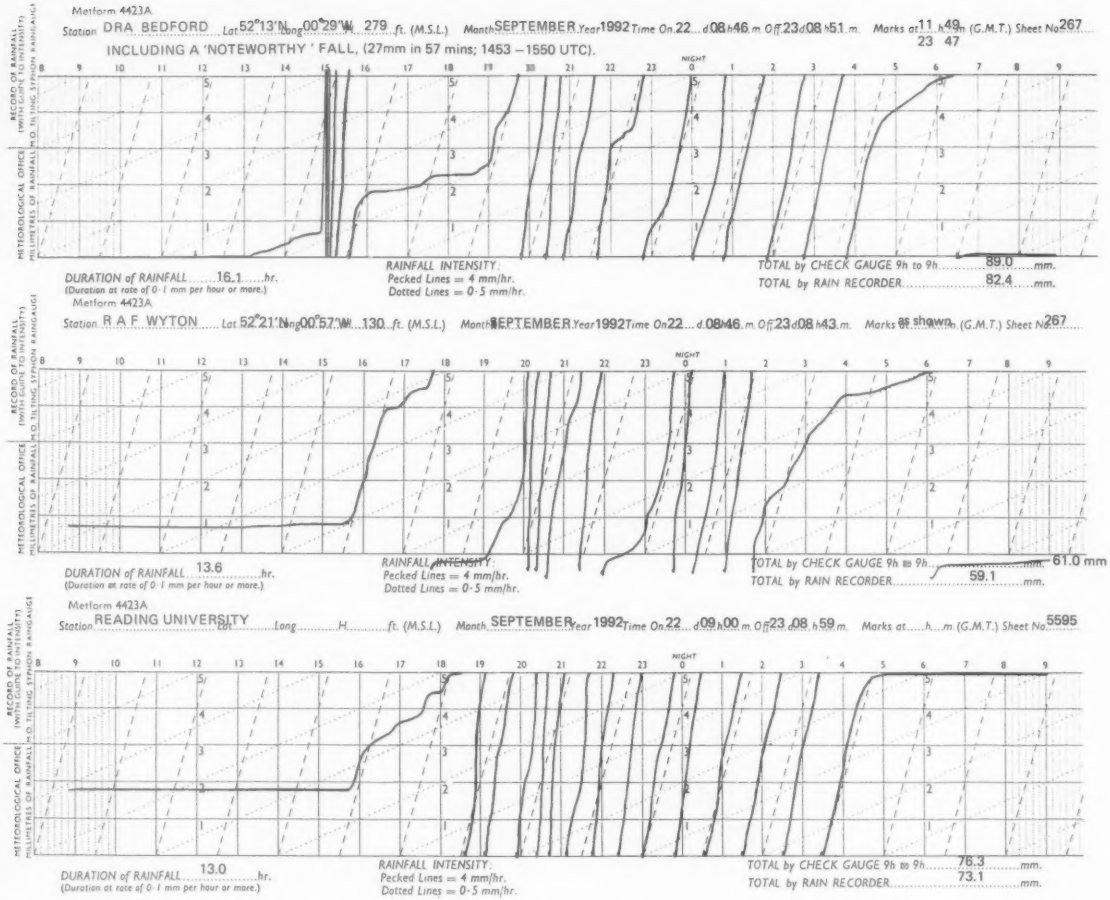
Metform 4423A
Station DRA BEDFORD Lat 52°13'N Long 00°29'W 279 ft. (M.S.L.) Month SEPTEMBER Year 1992 Time On 22 d 08 h 46 m Off 23 d 08 h 51 m Marks at 11 h 49 m (G.M.T.) Sheet No 267
INCLUDING A 'NOTEWORTHY' FALL, (27mm in 57 mins; 1453 – 1550 UTC).
23 47
DURATION of RAINFALL 16.1 hr.
(Duration at rate of 0·1 mm per hour or more.)
RAINFALL INTENSITY:
Pecked Lines = 4 mm/hr.
Dotted Lines = 0·5 mm/hr.
TOTAL by CHECK GAUGE 9h to 9h 89.0 mm.
TOTAL by RAIN RECORDER 82.4 mm.
Metform 4423A
Station R A F WYTON Lat 52°21'N Long 00°57'W 130 ft. (M.S.L.) Month SEPTEMBER Year 1992 Time On 22 d 08 h 46 m Off 23 d 08 h 43 m Marks at shown (G.M.T.) Sheet No 267
DURATION of RAINFALL 13.6 hr.
(Duration at rate of 0·1 mm per hour or more.)
RAINFALL INTENSITY:
Pecked Lines = 4 mm/hr.
Dotted Lines = 0·5 mm/hr.
TOTAL by CHECK GAUGE 9h to 9h 61.0 mm
TOTAL by RAIN RECORDER 59.1 mm.
Metform 4423A
Station READING UNIVERSITY Lat Long H ft. (M.S.L.) Month SEPTEMBER Year 1992 Time On 22 d 09 h 00 m Off 23 d 08 h 59 m Marks at h m (G.M.T.) Sheet No 5595
DURATION of RAINFALL 13.0 hr.
(Duration at rate of 0·1 mm per hour or more.)
RAINFALL INTENSITY:
Pecked Lines = 4 mm/hr.
Dotted Lines = 0·5 mm/hr.
TOTAL by CHECK GAUGE 9h to 9h 76.3 mm.
TOTAL by RAIN RECORDER 73.1 mm.

Figure 5. Tilting-siphon rate-of-rainfall records for the 24-hour period ending 0900 on the 23 September 1992 from (1) DRA Bedford (top), (2) RAF Wyton (centre) and (3) University of Reading (bottom).

England: 50 mm or more fell in 24 hours over approximately 1160 square kilometres, with more than 75 mm over 125 square kilometres. The heaviest rain was mainly over modestly rising ground to the west of the Fens.

Parts of Buckinghamshire, Hertfordshire and Berkshire also had totals over 70 mm. Over the relatively dry ground at that time this appears to have been the threshold for flooding, locally severe around the Silkstream in Edgware, or long-lasting flooding, notably the River Great Ouse around Bedford.

According to the Bilham classification of heavy precipitation in short periods, there was one remarkable fall and several noteworthy ones during convective activity on 22 September. Some evidence for orographic enhancement of these showers and thunderstorms was found. Other factors believed to have been ingredients responsible for intensification of precipitation were:

(1) Formation of a mesoscale warm-frontal wave which moved northwards over western Fenland during the afternoon and evening of Tuesday the 22nd.

(2) Formation of convergence lines later in the afternoon of the 22nd (particularly one near the Somerset–Dorset border).

(3) Arrival of an upper level low from the south-west.

Not since 14–15 September 1968 has such a large area of heavy rainfall occurred over the south-eastern half of England in September.

Acknowledgements

At the Met. Office, Bracknell (HQ), special thanks to Pete Newcomb and Steve Barker for the radar imagery used for Fig. 3; also to Mick Wood and Staff of Archives in Scott Building for supplying data upon which Figs 1 and 2 have been drawn; also especially for use of the A2 copier which enabled data from several hundred raingauges to be compiled on a large-scale OS NGR British Isles chart used as a step towards Fig. 4.

Additional rainfall reports came from Met. Office Data Services, Johnson House, Bracknell; and more numerously from the National Rivers Authority Anglian and

Thames Regions (thanks to Allan Bond, Lincoln; Diana Butcher, Reading, and Bob Hillier, Brampton).

I am indebted to the Senior Met. Officers at Bedford, Wittering, Wyton and Yeovilton for sending their rainfall data, particularly forms F4423A where available, for use in Fig. 5.

I am also very grateful to K. Spiers, met. observer at The University of Reading, for sending his F4423 (which was 'worked up' on an F4423A to complete Fig. 5). Thanks also go to Malcolm Wickenden (East Malling) and to Andrew Lee (Institute of Hydrology, Wallingford) for their additional F4423s not included in this article, they were much appreciated.

Additional rainfall data came from the Climatological Observers' Link September Bulletin, also from Terence Meaden and Jonathan Webb (TORRO), and thunderstorm reports were freely made available by Keith Mortimore (Director of TCO at Corsham).

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Location of frequent ground strokes

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Thunderstorms of the 8–9 August 1992. *It was originally my intention to run a long article by Mr. Pike on these storms but time and lack of space has prevented that. Instead, he will present that work at the Royal Meteorological Society meeting on Saturday 22 October 1994 in the meeting he is organising called 'Thunder, lightning, hail and tornadoes'. However there is room this month to print his supplement on the electrical activity and a technical note on the system with which gathered the data he mentions.*

Despite reports that much of the lightning activity over the southern United Kingdom during the storms of 8–9 August 1992 was inter- or intra-cloud, over 85 000 strikes to ground ('ground strokes') were detected by the Electricity Association (EA)'s lightning location system over that 48-hour period. The EA system is described later.

The current (*1992 — Ed.*) network (Fig. 1) consists of five ground stations (Melbury, Thetford, Churton, Harwood and Rhynie) and is capable of storing up to 40 strikes per second for later analysis. Information on strikes (up to 4 hours old) is displayed graphically as coloured dots on a VDU map, although currently, the screen only has a capacity to display 1000 strokes, with all earlier discharges being removed.

Fig. 2(a) shows a rather persistent storm having passed from south-east Devon to the Severn Estuary during the past 4 hours; with a new storm over central southern England. This was the beginning of 'Storm Area 1' (after Hewson (1993)) that was soon to be responsible for causing £23 000 worth of damage to a house at Hampstead Norreys (just to the north-east of Newbury, Berkshire) which was struck at 2105 UTC (personal correspondence with Mr R. Chapman).

Figure 1. Location of the current direction finding stations. The area of coverage approximates to the area shown. Western Eire is not fully covered.

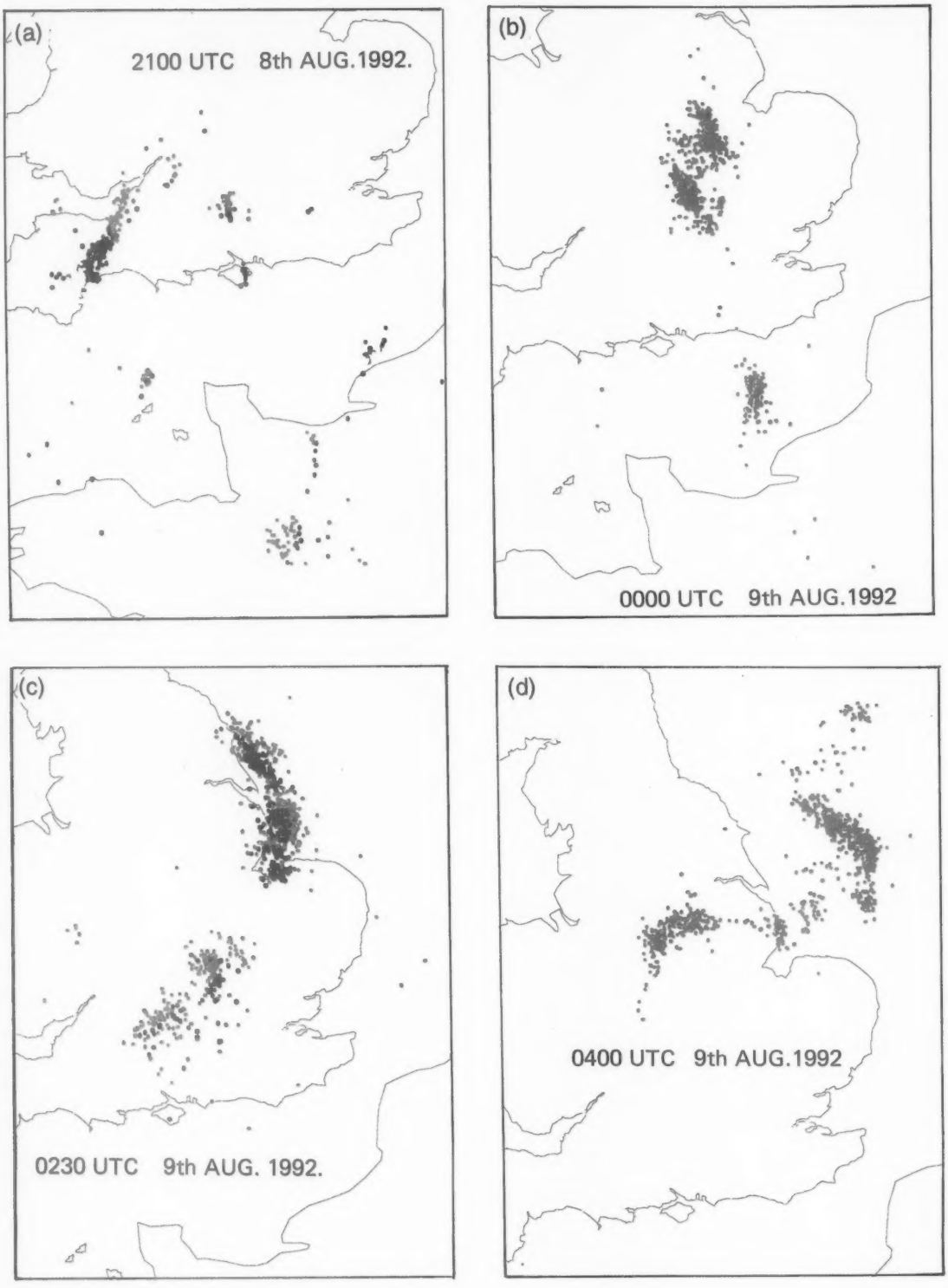

Figure 2. Ground strokes registered by the EA Technology lightning location system. Times are shown within Figures. Key — Strikes in the last 10 minutes, red: 10–20 minutes, green: 20–60 minutes, magenta: 1–2 hours, blue: 2–3 hours, black, and 3–4 hours, yellow.

Fig. 2(b) shows 'Storm Area 1' over Northamptonshire at 0000 UTC on the 9th, with a new 'Storm Area 2' (after Hewson (1993)) moving northwards from the Le Havre area of France. Note that even with 1000 ground strokes displayed, nothing over 20 minutes old appears on the screen! Fig. 2(c) shows a temporary diminution in lightning frequency with 'Area 1' leaving the Lincolnshire–Yorkshire coastline and 'Area 2', having formed a line of activity, moving north-northwestwards over central southern England and northwards into the east Midlands.

Fig. 2(d) shows storm 'Area 1' moving away northeastwards over the North Sea, with storm 'Area 2' continuing northwards as a dinstinct line (the discharges being particularly numerous at this time in the Sheffield–Doncaster area of South Yorkshire). Note that most of these ground strokes registered over just the past 10 minutes, indicating the extreme intensity of these two storms combined. In moving some thirty degrees to the right of 'steering' winds, storm 'Area 1' was behaving like a 'supercell' (after Browning (1962, p. 349)).

Acknowledgment

Images were kindly supplied by Terry Morgan at EA Technology, Capenhurst, Chester.

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Lightning flash location

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1. Uses

Lightning damage of the distribution system is believed to cost the Electricity Companies in the UK some £4m annually. However, until recently the position, severity and influence of individual strikes has been virtually unquantified.

The National Lightning Flash Location System, developed by EA Technology, has not only made the collection of such data possible, but also provides near 'real-time' presentation of the information on the VDU of a personal computer.

2. Benefits

— Early warning of the approach of a storm enables control staff to prepare for the storm in good time, before problems occur.

— Strike information is received within seconds of the occurrence, making it possible to follow the progress of a storm as it moves across the country and assisting in the management of overhead line working, increasing both the safety of personnel and the efficiency of such operations.

— Faster re-establishment of lost supplies following a storm is possible as personnel can be moved into the path of a storm ready to repair the damage, rather than having to wait for notification of the damage before moving to its location.

— As well as 'live' use of the system, the data is stored for later replay and analysis. This will be used in the longer term to relate equipment failures to lightning occurrence. The effectiveness of protection equipment can be better assessed, by comparing the performance of the network before and after protection equipment was fitted, with a knowledge of the incidence and severity of lightning activity.

— Ground strike density and stress maps are being built up by EA Technology to assist in deciding where protection equipment would be best utilized.

3. Technology

Damage to the electricity distribution network, and to other earth-based structures, is caused by cloud-to-ground strikes These make up a third of all lightning strikes: the remaining two thirds occur within clouds or between clouds. It is important to differentiate between these types, since often lightning may be seen but no damage occurs. For this reason, the EA Technology system has been designed to locate only cloud-to-ground strikes, because its primary purpose is for assessing, locating and to some extent predicting damage.

EA Technology's system uses radio direction finding techniques to locate the lightning strikes. At the frequencies commonly used for direction finding, the radiation from the lightning strike can be regarded as propagating as two waves — one which follows the ground ('ground wave' — vertically polarized) and one which is reflected from the ionosphere ('sky wave'). This 'sky wave' (horizontally polarized) is superposed on the ground wave and can result in the direction finding station reporting an erroneous bearing. In order to avoid this effect, the EA Technology system uses an extra-low frequency (ELF)

of 1.1 kHz with a bandwidth of 350 Hz. At this frequency the earth's surface and the ionosphere act as conducting shells separated by an insulating gap of between 50 and 100 km. This is less than half the wavelength range of 235 km to 325 km which can be 'seen' by the EA Technology direction finders. The cut-off frequency of the waveguide for horizontally polarized waves (sky waves') is above 1.3 kHz, and therefore these do not propagate to any significant extent.

The ELF waves generated in the gap and propagated around the earth in this two plate waveguide are only the 'ground waves'. As there is no 'sky wave' at the operating frequencies, the bearings produced are more accurate than conventional systems.

Because inter- and intra-cloud strikes mainly produce horizontally polarized radiation, a further advantage of using this frequency is that they are not registered by the system unless they are very close (within 30 km) to a direction finding station.

A number of direction finding aerials around the UK report 'sight' of a lightning strike to a central computer at EA Technology. The strike reports are processed and then reported to on-line subscribers at a rate of up to 5 strikes per second. Up to 40 strikes per second can be accepted and stored or later analysis.

4. Specification and outputs

Users of the system can receive on-line information on the location, time and strength of lightning strikes within the United Kingdom and the north-west coastal regions of continental Europe. The information is stored by the user's personal computer and the strike is instantly displayed graphically on a VDU map. Stored data can be replayed at accelerated speed over any chosen time period, colour prints of the display map showing all strikes within a given period and area can be produced, alternatively a list of strike information within a given period can be printed. The data may also be used for more-detailed analyses of lightning trends, or for assessing the suitability of protection schemes.

The display software runs on an IBM compatible PC within the Microsoft 'Windows' environment. The program is menu driven. It is controlled using a 'mouse' to position a cursor on the screen and select a command or item. Flashes are displayed within seconds of their occurrence on an outline map of the British Isles and the north-west coast of continental Europe. Pan and zoom of the display is provided, varying the vertical dimension of the screen from 50 km to 1600 km. Various overlays are available displaying the 400 kV, 275 kV and 132 kV network, power stations and substations. User-defined overlays are easy to produce and can be included in the display.

The strike position indicators are colour coded, representing the time of the strike. Data on any specific strike an be extracted by positioning cross hairs over the strike using the 'mouse' and clicking the 'mouse' button. A window opens which shows the details of the strike including the latitude, longitude and Ordnance Survey National Grid reference of the strike position, the uncertainty in the fix, the current of the strike, the date and time to the nearest hundredth of a second. In addition a multiplicity counter is reported for restrikes. A colour printer provides hard copy of both the screen display and details of strikes within a given time period.

5. EA Technology services

Although the system was initially developed and installed for the UK electricity companies, services are now available from EA Technology which would be of value to any organization whose operations and profitability could be affected by lightning activity.

Services are customised to suit an individual organization's needs. They range from full on-line display of lightning activity to the occasional provision of historic data, and can include analysis by EA Technology's team of lightning specialists if required.

For further information about the Lightning Flash Location system, how it has developed since September 1992, and the services available, please contact:

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CH1 6ES
UK

Direct dial: 051-347 2554
Direct fax: 051-347 2305
Telex: 627124 RESELEC G

Postscript

The storms did not pass unnoticed at sea; below is a report printed in The Marine Observer, *Volume 63, No. 321, July 1993. the* Marine Observer *is published quarterly for the Meteorological Office by HMSO for £5, annual subscription £19 including postage.*

Passage of a squall — North Sea

m.v. *Drupa*. Captain A.J. Howe. At anchor, Dogger Bank. Observers: the Master and Mr J. M. Bastone, 2nd Officer.

9 August 1992. At 0445 UTC whilst awaiting orders weather and sea conditions were noted as: pressure 1009.7 hPa, wind E'ly, force 4, sky cloudy but not overcast, light sea with no swell. Shortly afterwards occasional thunder was heard and lightning was seen astern (the vessel's heading being 054°) and at 0455 the wind was noted to veer and increase to force 6 with gusts to 30 knots. The cloud cover changed to 8 oktas of stratus, the pressure rose vertically, being 1010.1 hPa at 0500, there was constant heavy rain which severely restricted visibility while continuous thunder and lightning (sheet and forked) was observed. These conditions lasted for 15–20 minutes and at 0518 the rain ceased, the wind decreased to W'ly, force 3–4 while the thunder and lightning became distant and sporadic. The sea was till light, but the vessel was now rolling slightly to a moderate south-westerly swell.

During the heaviest rain the radars showed a dense cloud running in a north/south direction; it was 4–5 n mile wide and about 25 n mile long, completely engulfing the vessel (good old *Drupa*, right in the wrong place again). At 0540 the pressure was falling vertically, reading 1008.9 hPa at 0545 and behaving like a yo-yo, the wind was N'ly, force 3, and there was moderate rain falling from 8 oktas of cloud. Thunder was again present at and around the vessel as lightning was observed to strike the sea 120–150 m away from it, rather too close for comfort.

Apart from the observers, the ship's company apparently slept through the entire event.

Position of ship: 54° 30′N, 02° 18′E.

Images in Weather Forecasting

A practical Guide for interpreting Satellite and Radar Imagery

Edited by M.J. Bader, UK Meteorological Office
G.S. Forbes, Pennsylvania State University, U.S.A.
J.R. Grant, UK Meteorological Office
R.B.E. Lilley, UK Meteorological Office
A.J. Waters, UK Meteorological Office

The aim of this manual is to present the meteorology student and operational forecaster with the current techniques for interpreting satellite and radar images of weather systems in mid-latitudes. The focus of the book is the large number of illustrations, many of them in colour. Images are matched with conceptual models and weather charts. Written in an image-led mode, rather than in the style of a standard textbook on meteorology, the presentation allows the user to identify and interpret patterns on the images as easily and quickly as possible. Patterns observed in satellite and radar images are explained in terms of basic airflows. Examples are presented showing variations on the basic patterns.

Material for the book has been provided by experts from North America and Europe, and reviewed by people from universities, training establishments of meteorological services and operational forecasters.

The project has been backed by Eumetsat and WMO and will be published later this year by Cambridge University Press.

Contents

Introduction to satellite and radar images — basic principles and simple interpretation. Interpretation of synoptic-scale cloud and moisture patterns. Fronts and waves. Depressions in mid-latitudes. Convective cloud patterns. Fog and low clouds. Orographic and polar phenomena. A Glossary of common terms and abbreviations.

For further information about the manual, please phone Joann Motherwell, Science Marketing Controller on 0223 325781, or write to Science Publicity at Cambridge University Press, The Edinburgh Building, Shaftesbury Road, Cambridge, CB2 2RU, UK.

It is not usual for this journal to print reports by those with no meteorological knowledge! However the events of this night were unusual on two counts. First, the event took place very close to an official meteorological observing site (03693), one with a radiosonde unit no less! More remarkably, of the few witnesses there were, most were police, trained to observe and record, and these included one whose standard of English is of the simple, straightforward type I am always hoping to find. It should be noted that all times in the witnesses' statements are BST which is UTC+1; meteorological data is UTC as normal.

Credit is also due to Robert Holborn *at the Shoeburyness meteorological office for collecting the reports and photographs. To me, an unusual aspect of the storm is list of casualties amongst the bird population. Although it seems obvious that such a storm should kill practically every bird in its path, this is either rare or goes unremarked. It may be that they were roosting and missed the signals that normally save them; on the other hand, about the only shelter on Foulness is designed to protect humans from straying artillery shells. Thanks to the presence of mind of some Churchend villagers some hailstones were refrigerated. On measurement the approximate average size was 25 mm diameter, with the largest measuring 48 by 42 mm.*

The surface charts show a small low drifting eastwards over the western English Channel with a cold front moving north-eastwards over south-east England.

551.578.71:551.577.61(410.113)

Hailstorm at Foulness — eyewitness accounts of the storm on Friday 18 September 1992

Sergeant G1091 V. Thicke MDP and Constable G725 I. Bailey MDP

It seems inappropriate to label the weather conditions on the night of Friday 18 September 1992 as simply a thunderstorm because they were of such epic proportions. In my view it could only to be equalled by the gale force winds of a couple of years ago when Michael Fish assured us that there was NOT going to be a hurricane, only to wake up the next morning to find such devastation.

Only twice in my life has the weather been so bad that it numbed my mind. The first was waking up the morning of the hurricane and wandering the streets in a daze, unable to comprehend the damage caused. The second was on the night of 18 September 1992.

Together with Constables Ian Bailey, Terry Turner, Martin Warwick and Ken Holland, I was on night shift at AWE Foulness. The night was much the same as any other night, although there was a thunderstorm rumbling around the other side of the estuary in Kent. Storms at night are generally spectacular when viewed from almost anywhere on Foulness and that night was no exception.

About 0200 on Friday morning the storm reached us and it was fairly obvious that this one was going to be really spectacular. The lightning was so frequent that it was almost like daylight. From Shelford Gate it was possible to see all of Havengore and down as far as Churchend. Ian Bailey was out on foot patrol and he said that from where he was in the middle of the Establishment he could quite clearly see the AWE perimeter fence. The frequency of the lightning was unsettling both Ian and his police-dog so he decided, fortunately as it turned out, to return to Shelford Gate for a break. In Ian's own words, the lightning was like staring into the strobe lights at a disco, it was making me feel giddy and affecting my balance, and the thunder was as if the whole range had opened with activity at every battery.

At about 0235 the rain became torrential. The road outside the Police office at Shelford Gate suddenly had so much water on it that the gutters couldn't manage and there was a lake of water 2 inches deep threatening to come through the doors.

At 0250 Martin Warwick and I heard the first hailstones tapping on the windows. At that point it was just the occasional one and did not seem very ominous, but suddenly it sounded as though there were a thousand people outside throwing stones at the windows. Visibility was cut to only a matter of about 50 feet and I honestly thought that the window were going to crash in. I got up from my desk and stood in the middle of the room so that any breaking glass, hopefully, would not reach me. The noise was so great that it was almost impossible to hold a conversation, and in a matter of minutes the road outside was covered with hailstones the size of golf balls. It looked as if it had been snowing steadily for a couple of hours and the snow had settled.

At this time Ian Bailey was about half a mile from the office. He said afterwards that there was suddenly a very loud rumbling noise off to his right. He could not make out what it was, and knew it had not been there earlier in the night. He thought that maybe there had been a lightning strike and the lightning had somehow started up a large generator. Suddenly he felt as if he were being stoned to death. He held his cap against the side of his head to stop the stones hitting him and headed for the office.

Back in the office I was trying to contact him by radio to see if he was all right. I could not get through. All of a sudden he stumbled through the doorway and just stood

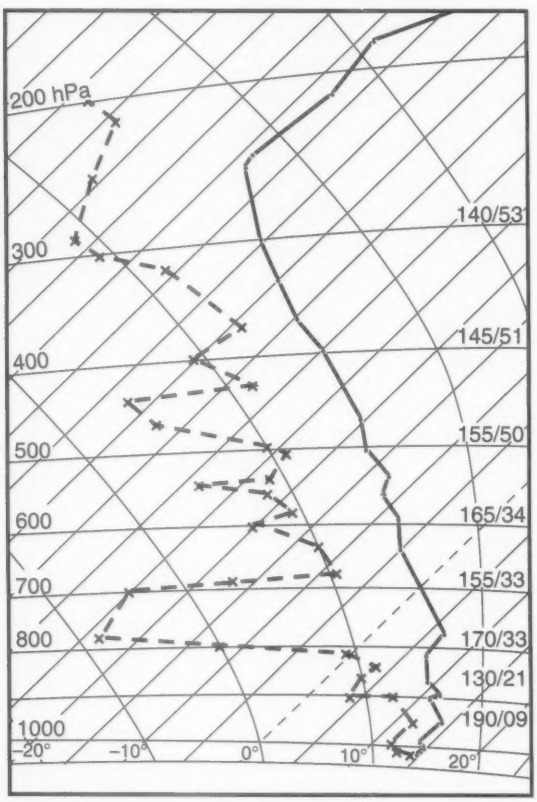
(Top) a typical sample of hailstones which fell on Foulness Island, and (bottom) indentations caused by hailstones on a villager's car during the storm.

there. He said that he had never been so frightened in all his life and had really thought that he would not make it back. From the look on his face that night I can believe it. At this time hail was coming from a southerly direction.

At about 0305 the hail stopped, and within a matter of seconds the building was engulfed in dense smoke drifting in from the north-north-west. We thought that there had been a lightning strike somewhere and that something was on fire so Ian Bailey and Martin Warwick went out in the landrover to check. The road outside the office was still flooded with water and they both got very wet feet getting to the vehicle. As it turned out there was no fire and the smoke was in fact a very thick mist which had appeared from almost nowhere.

When they got to the vehicle they called me out of the office because the landrover had been badly damaged. Almost every panel on the landrover was covered with dozens of dents caused by hailstones striking it. It was at this point that we realised that our private cars were also parked there, a quick inspection showed that all our private cars had also been extensively damaged. One

Chenies radar data on 18 September at (left) 0215 and (right) 0315 UTC. Colour code is shown at bottom left. L = trace, 1 = >1 mm h^{-1}, 4 = >4 mm h^{-1}, etc. and T is <16 mm h^{-1}.



Shoeburyness tephigram for 0700 UTC on 18 September 1992.

private car had a broken windscreen, and the blue light on the landrover had been smashed.

Shortly after this there was another downpour of hailstones for about 5 minutes, but these appeared to be coming from the north. The area of the hailstorm covered the whole of the AWE site area.

At 0530, over 2 hours after the storm, when I handed over to my relief, the area outside the office was still covered with hailstones, and they had not noticeably diminished in size.

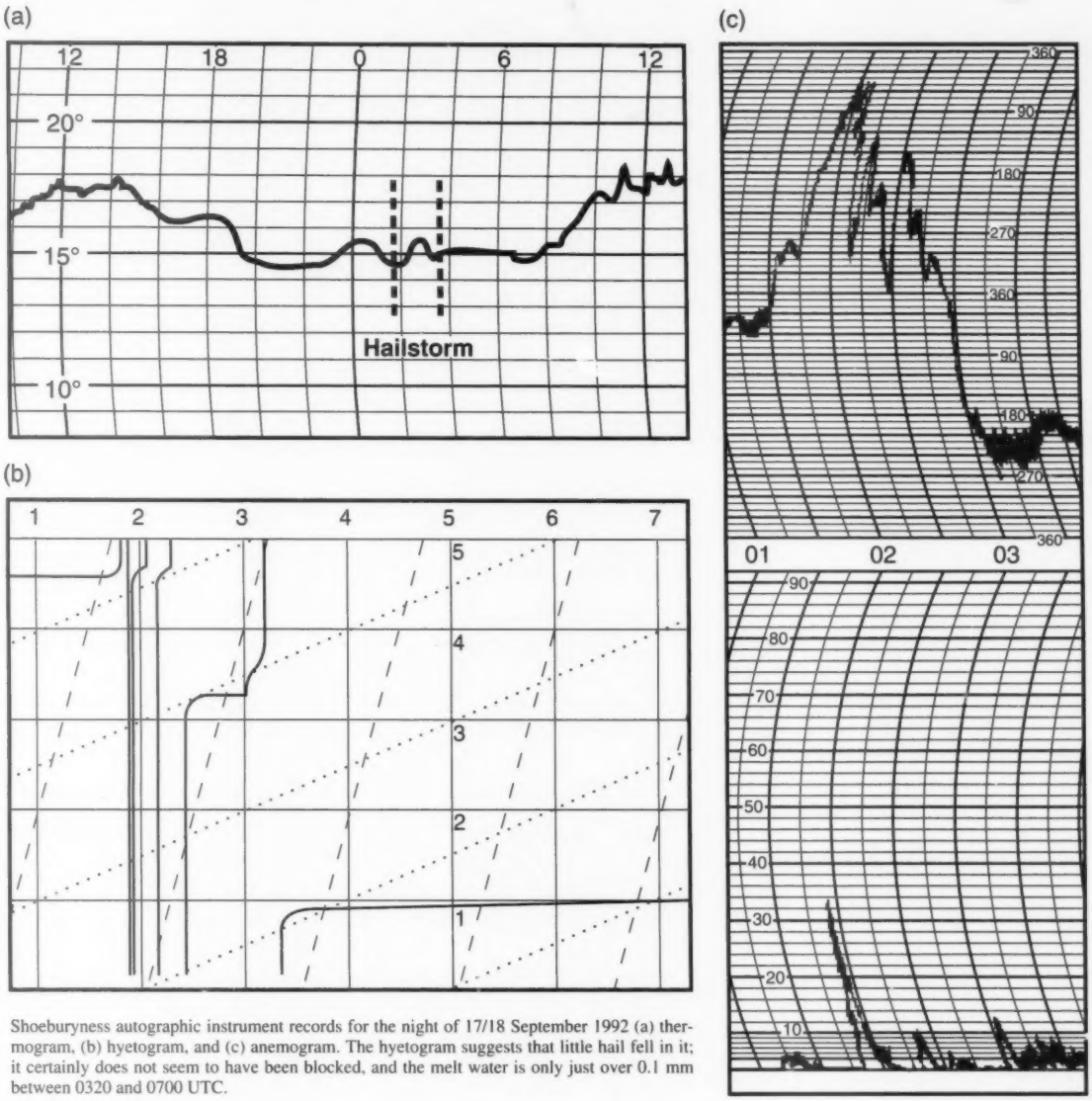
The road between AWE and Landwick was still flooded in places, and scattered with debris from the trees where the hailstones had broken small branches and almost denuded the trees of leaves.

During the height of the storm we were waiting with baited breath for the phones to ring for we knew that if the hailstones were very widespread we should all have our wives calling to say that our homes had been damaged. Fortunately that was not the case and if it had not been for the damage to our private vehicles, they would probably not have believed us.

The next day when I took my car to the garage to have the damage estimated for repair, the estimator was amazed at the damage and said "I live in Great Wakering, and I heard the thunderstorm last night, but we never had any hailstones at all".

Eyewitness account of the storm by M. Hume

I live at 32, Churchend and was woken by the thunder at about 3 a.m. on 18 September. At about 3.15 I was standing in our conservatory when there was a bang on the corrugated perspex roof, which was the first of the hailstones. The next one came straight through the roof in



Shoeburyness autographic instrument records for the night of 17/18 September 1992 (a) thermogram, (b) hyetogram, and (c) anemogram. The hyetogram suggests that little hail fell in it; it certainly does not seem to have been blocked, and the melt water is only just over 0.1 mm between 0320 and 0700 UTC.

front of me. This one was about one inch in diameter. The hailstorm lasted for about 15 minutes. The largest hailstone I saw was about the size of a large chicken egg. The noise of the storm was deafening, even drowning out the sound of the thunder.

The storm totally destroyed our conservatory roof, greenhouse roof and punched holes in the guttering around the house and garage, also breaking and cracking slates on the house roof. The ground was completely covered by the hailstones after the storm and these lasted for quite a few hours. The next morning I was amazed to see dents 5 mm on the cars in the village that had been left outside during the storm.

Wildlife casualties compiled by Mr Adcock

Table I is a list of dead birds found after the hailstorm. The exact number was probably higher as many were washed out to sea. Many suffered broken bills, wings, legs and smashed skulls. RSPCA inspectors were called in to help dispatch the badly injured. High tide on that morning was at 0435 and by 0230 waders were already beginning to congregate towards the high water mark. It was this factor that probably resulted in the large number of waders being killed. Pheasants and partridges are bred at Rugwood Farm. It was this grouping that accounted for the high number of game bird fatalities. One sheep and eight hares were also victims of this storm.

Table I. Bird casualties in the Foulness hailstorm

Cormorant	2	Blackheaded Gull	817
Grey Heron	3	Common Gull	195
Wigeon	1	Lesser Black-backed Gull	7
Tufted Duck	1	Herring Gull	53
Sparrowhawk	2	Great Black-backed Gull	7
Partridge sp.	3	Gull sp.	42
Grey Partridge	142	Sandwich Tern	3
Red-legged Partridge	526	Common Tern	3
Pheasant	107	Black Tern	2
Oystercatcher	267	Guillemot	1
Ringed Plover	2	Stock Dove	10
Golden Plover	14	Woodpigeon	30
Grey Plover	140	Collared Dove	2
Lapwing	1	Turtle Dove	4
Knot	9	Barn Owl	3
Curlew Sandpiper	1	Skylark	5
Dunlin	93	Meadow Pipit	3
Bar-tailed Godwit	210	Blackbird	1
Curlew	43	Magpie	5
Redshank	260	Starling	211
Turnstone	6	House Sparrow	1

551.556.42:77

Features of a smoke plume determined from successive photographs

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Two pairs of successive photographs of a combustion-generated smoke plume taken during a tropical land-breeze episode were analyzed to determine some geometric (horizontal and vertical extensions) and kinetic (velocities of inner masses) features of the plume. The times between photographs were 3.5 s (first pair) and 6.1 s (second pair).

In the tropics, information concerned with smoke plumes and local winds is important for many petrochemical industries, but surface wind data from only a few coastal land stations are available. Here, I am reporting a successful attempt to get information about a combustion-generated smoke plume during a land-breeze (low-speed) episode using successive photographs taken in a tropical bay (Ocumar Bay) on 30 March 1991. I have followed basic ideas by Sutton (1953) on smoke photographs and Smith (1967) on airborne tracers in agricultural meteorology, but using two pairs of successive photographs and plume inner masses as airborne tracers. The time between the photographs of each pair is less than 10 seconds and the time between pairs is nearly a minute. The use of plume photographs has also been reported by Hanna and Perry (1973). Rickel *et al.* (1990) and Templeman *et al.* (1990) have reported the use of video digitization. Smith (1992) has pointed out the importance of low wind-speed meteorology.

The pairs of photographs were taken and the prints were analyzed to determine some geometric (horizontal and vertical extensions) and kinetic features (velocity of inner masses) of the plume. See the first photograph of the first pair in Fig. 1. A land breeze and an inversion above the top of the plume may be inferred by visual inspection of Fig. 1. The photographs, with the smoke source near their centre, were taken toward the ESE from

Figure 1. First photograph of the smoke plume taken on 30 March 1991 (0721 LT (1152 UTC) 10° 29′N, 67° 46′W, 5 m AMSL, Ocumare Bay, Venezuela, southern coast of the Caribbean Sea).

a distance of 1350 m, at right angles to the plume which was pointing to the NNE, toward the sea. The time between photographs were 3.5 s (first pair) and 6.1 s (second pair). Figs 2(a) and 3(a) show outlines of a 314 m sector of the plume.

The analysis combines visual inspection and measurements of distances on the prints (in millimetres) that are transformed into true distances (in metres) using a photograph scale determined by the following procedure. Photographs of pipelines and buildings were taken of a petrochemical industrial area, After comparing those photographs with maps, it was found that the field of view of the camera is 38° wide. A similar procedure was used for Ocumare Bay obtaining a similar angle. That angle gives a view of 930 m wide and 628 m high for a photo taken from 1350 m when the print is 148 mm wide and 100 mm high. Those values lead to a 1:6280 photographic scale on a virtual vertical plane containing the plume centre line, assuming minimum optical distortions. Using a print with those sizes and the above scale, it is possible to obtain a horizontal plume extension of 434 m for Fig. 1, measured downwind from the smoke source centre.

For the determination of velocities five masses were marked in the first pair of prints (A–E) and six masses in the second pair (F–J) and the coordinates (x, horizontal; z, vertical) were measured in millimetres of print with respect to a fixed frame. Later, by differentiation, the vertical and horizontal displacements of masses were

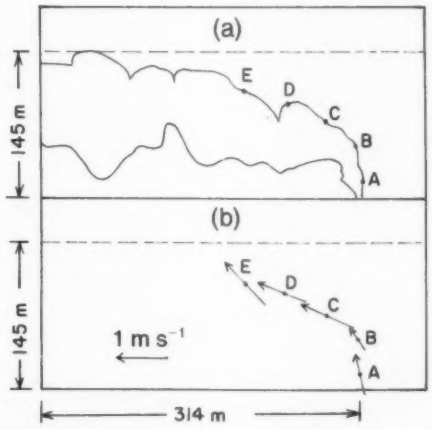

Figure 2. Outline of the plume (a) and velocity vectors of inner masses determined from the first pair of photographs (30 March 1991; 0721 LT; 3.5 seconds between photographs). Masses labelled with letters (A–E) should be interpreted as airborne tracers.

computed in millimetres of print. Using the photographic scale, the displacements in millimetres of print were converted into true metres and these last values were converted into speeds by dividing by the time between photographs. Table I presents the speeds. Figs 2(b) and 3(b) show the composite velocity vectors. The horizontal wind speed is nearly equal to the horizontal speed of any mass.

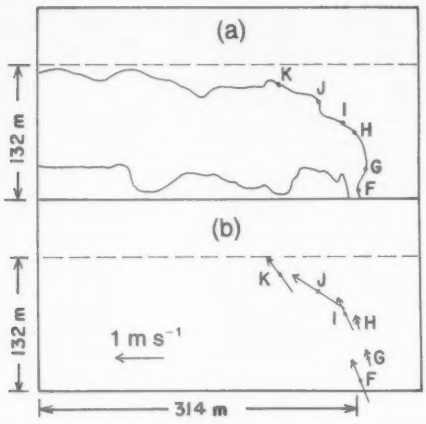

Figure 3. As Fig. 2, but for the second pair of photographs (0722 LT (1152 UTC); 6.1 seconds between photograph).

Table I. Horizontal (u, m s^{-1}), vertical (w, m s^{-1}) and composite (v, m s^{-1}) speeds determined from the photographs

Mass	u	w	v
A	0.2	0.8	0.8
B	0.3	0.4	0.5
C	1.0	0.4	1.1
D	1.0	0.4	1.1
E	0.8	0.8	1.1
F	0.3	0.8	0.9
G	0.1	0.3	0.3
H	0.1	0.3	0.3
I	0.3	0.7	0.7
J	1.0	0.7	1.2
K	0.5	0.7	0.8

$v = (u^2 + w^2)^{1/2}$

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Reviews

Advances in Bioclimatology. Part 1, by R.L. Desjardins, R.M. Gifford, T. Nilson and E.A.N. Greenwood. 158 mm × 241 mm. Berlin, Heidelberg, New York, London, Paris, Tokyo, Hong Kong, Springer Verlag, 1992, pp. x + 157 Price DM 118. ISBN 3 540 53483 7..

Advances in Bioclimatology. Part 2 — The bioclimatology of frost, by J.D. Kalma, G.P. Laughlin and J.M. Caprio. 158 mm × 241 mm. Berlin, Heidelberg, New York, London, Paris, Tokyo, Hong Kong, Springer Verlag, 1992, pp. xvii + 144. Price DM 118. ISBN 3 540 53855 0.

This new review series under the general editorship of G. Stanhill, has the aim of 'providing a common forum for those wishing to obtain an authoritative review of the latest developments in bioclimatology. The emphasis will be on advances which are soundly based on biological and physical principles rather than those describing empirical relations'. Many of the reviews have been commissioned from internationally known authors. So far two books have been produced: book 1 with four contributions on several topics, and book 2 which concentrates on the bioclimatology of frost.

Book 1 begins with a chapter on techniques to measure CO_2 flux densities using surface and airborne sensors. The aerodynamic, energy balance, Bowen Ratio and eddy correlation techniques are described for surface-based instruments and their strengths and weaknesses highlighted. Aircraft-based measurements can give better spatial averaging and the author gives a critique of the methods which draws upon his own experience of using aircraft in this way.

The CO_2 theme is continued into chapter 2 where the impact of rising CO_2 levels on the growth-limiting environmental factors such as light, water, temperature and nutrients are discussed. Starting with Liebigs (1855) 'law of the minimum', the various interactions and feedbacks between CO_2 and other limiting factors in the crop growth system are used to show that reality can be different from this hypothesis. Because light, water and

nitrogen are used with greater efficiency at higher CO_2 levels there is a good prospect that the 25% rise in atmospheric CO_2 concentration in the past 100 years would be increasing net vegetation production and the storage of carbon as litter.

In chapter 3 attention is turned to the transfer of radiation in plant canopies which are not assumed to be homogeneous. Most earlier treatments of radiation extinction in plant canopies assumed spatial homogeneity. This ignored the actual growth habits of plants such as the clumping of leaves, or a row structure which is typical of farm crops. The more recent treatments consider the distribution of foliage within a canopy and a theoretical method is developed whereby the spatial non-randomness of foliage can be explained using models which group the foliage into sub-canopies. Within the sub-canopies a random dispersion of foliage elements is assumed.

The final chapter, which occupies nearly one-half of the book is about deforestation, revegetation, water balance and climate. This is a wide-ranging review of the issues involved in calculating water balance which discusses the assumptions made and the likely sources of error in the component parts such as precipitation, evaporation, run-off, subsurface flow, infiltration and soil water storage. The bulk of the review is concerned with the reported effects of deforestation and revegetation on the water balance. The general thrust supports the view that the replacement of trees by short-season arable crops can increase the water yield of a catchment because less water is used in evaporation. However, the reduced evaporation can cause reductions in rainfall in areas (e.g. Amazonia) which have a rapid evaporation–precipitation cycling of water. It has also been observed that clear-felling can increase the peak discharge of rivers and increase soil erosion. Another unfavourable effect of the removal of trees is to raise the level of groundwater. If this process should mobilise salt deposits, such as has happened in parts of Australia, then conditions may become unfavourable for the crops which have been planted instead. The writer of this chapter is optimistic that the challenge to hydrologists to change vegetation patterns without substantially altering the components of the water balance can now be adequately met.

The four chapters in book 1 are without doubt authoritative and provide a good update on the topics chosen. To this reviewer the second and fourth chapters are the better ones because they are entertaining as well as informative with hardly an equation in sight. The third chapter on radiation transfer is more difficult to follow and is really for those who are nearly expert in this area already.

Book 2 is about frost and it is aimed at researchers, engineers, extension officers and students as an aid in understanding the physical aspects of frost occurrence and distribution as well as the biological and phenological aspects of frost damage. An overview is also provided of direct and indirect methods of frost protection and prevention. The book attempts to : (1) provide a comprehensive review of advances in the past 10 years, (2) to draw together the wide range of physical, biological and engineering aspects, and (3) to draw on examples worldwide. The emphasis is on short duration frosts which would be of importance to agriculture and horticulture. Topics are restricted to the aerial parts of plants and aspects such as soil freezing for example are not considered.

The book has three parts: Part 1 (chapters 2–6) discuss the physical aspects of frost occurrence and distribution. Chapter 2 identifies the types of frost and describes the worldwide distribution of frost. There is some discussion of the impact of climate change on frost distribution and a short section on frost protection methods. The physics of night-time cooling of near surface air, ground and plant surfaces is discussed in chapter 3 and the relevant mesoscale processes such as katabatic drainage are reviewed and illustrated by a case study in chapter 4.

In chapter 5 there is a review of the techniques available for frost-risk mapping at the regional scale. The section ends with a review of the use of remote sensing in frost-risk mapping.

Part 2 (chapters 7 and 8) emphasises the relationships between frost (and other weather factors), crop growth and crop development. Topics such as plant hardiness, plant stress, frost resistance, chilling and plant rest requirement appear. Chapter 8 is devoted to a case-study of the factors which affect the winterkill of wheat in Montana (USA).

Part 3 of the book (chapters 9–11) is about frost protection methods. Frost amelioration can be active or passive. Active methods include the use of heaters, wind machines or by freezing water which is sprinkled on the crop. In chapter 10 a model to estimate the required rates of water application in sprinkler systems is described. Passive methods, which are described in chapter 11, include various management techniques such as increasing soil moisture (to raise the soil heat conductivity), growing taller plants (to raise susceptible plant parts out of the coldest air) and delaying the blooming of fruit trees by growth regulator sprays or by the chilling of flower buds using water sprays over a long period. The book ends with 15 pages of references from the past 30 years and a subject index.

This is a wide ranging and authoritative review with information on many topics. Particularly helpful are chapter 3 (microscale processes) which includes a model to estimate leaf temperature, chapter 4 on the mesoscale and chapter 5. In chapter 5 there is a comparison of two statistical methods (linear regression and spline fitting) which can be used to relate minimum temperatures to location and hence lead to mapping of frost prone areas. The role of local terrain on minimum temperature at a point is shown to be explainable in terms of the land area which could contribute to cold-air drainage to the point. Other topics are treated more briefly, but there are plenty of references to follow points of interest.

This pair of books is a good start to the series, though this reviewer found the book on frost rather the better of the two because of the unifying theme. Others in the series are eagerly awaited.

M.N. Hough

The atmospheric boundary layer, by J.R. Garratt. 177 mm × 253 mm, pp. xviii + 316, illus. Cambridge University Press, 1992. Price £50.00, $79.95. ISBN 0 521 38052 9.

To the uninitiated, boundary-layer meteorology presents if not a jungle, then a fairly dense canopy. Many students lose their way *en route* from Ekman pumping to the Penman–Monteith equation. It is sad if boundary layers remain an esoteric mystery, because of course a lot of practical weather forecasting (e.g. the difference between air-frost and ground-frost) is just boundary layer meteorology by another name. Now, too, climate research has focused attention especially on boundary-layer interactions with clouds and surface processes.

With an enviable combination of experimental and modelling experience, John Garratt is well placed to be a guide. This textbook is aimed at 'the experienced researcher or teacher working in the atmospheric or related sciences'. It forms part of the new 'Cambridge Atmospheric and Space Science Series', (editors include Sir John Houghton) — at present a fascinating collection of six titles including two on plasma physics.

In terms of Royal Meteorological Society journals the style is mostly '*QJ*' rather than *Weather*, but long mathematical derivations are avoided. Both descriptive and mathematical parts are exceptionally lucid. Some readers of *Meteorological Magazine* will find parts quite difficult, but will still gain real insight into current boundary-layer research issues if they persevere.

Deliberately, and I think rightly, the author ignores experimental and numerical techniques; a superficial discussion of these highly technical issues would not be useful. Similarly, and wisely, the very important and closely related issues of air pollution are not covered. Instead, the slant is towards climate or forecast modelling.

The introductory chapters (1 and 2) give both a descriptive summary of boundary layers and turbulence and a fairly thorough account of mean-flow and second-order budget equations. Classical similarity theory (3; always a delicate subject) is well handled, though the devil's advocate might argue that the Coriolis parameter is overrated in boundary-layer scaling. I particularly enjoyed the chapters (4 and 5) on surface and radiative processes. The thermally stratified boundary layer (6; somewhat neglected in 'dynamics' books) has a good airing. Cloud-topped boundary layers (7) represent a fast-moving and important sub-field; Garratt perceptively notes that the current theories of stratocumulus break-up disagreed with observations. The book rounds off with modelling and parametrization (8) and climate applications (9), including 'research priorities' which seemed balanced, though I am not a climate modeller.

In assessing the up-to-dateness and accuracy of discussion of recent research, the reviewer inevitably focuses on the work of his closest contacts (in my case, physical research groups in the Meteorological Office). Work by P.J. Mason and co-workers on non-uniform or hilly terrain and on boundary layer simulation gets reasonable coverage. I found the brief summary of my own recent work fair. The cut-off date seemed to be around 1990; papers from that year on stratocumulus by MacVean and Mason and R.N.B. Smith, and also work on stable boundary-layer simulation, might rate a mention in a second edition. The author's recent affiliations are American/Australian, and the coverage of other recent work seems good also.

Now for the nit-picking. The paper quality is not glossy (environmentally sound? perhaps a good thing), and a few pages in my copy were slightly smudged. A few obvious typos in the text ('Bachelor', 'Cabaow', 'mesosphytes'), but the equations seem OK. The younger generation will enjoy a smirk at 'degrees kelvin' (p. 128), though the adherence to SI units (plus the politically correct hectopascals) is commendable. There is little else to gripe about really. The index, bibliographies and appendices are good.

The publishers seem nervous that recent textbooks might have cornered the market. They need not worry too much: despite some competition, this is the best introduction to the subject, particularly from the standpoint of modelling, that I have read. The price may put a strain on the student's bank manager, but any researcher with interests in boundary-layer meteorology should have access to a copy. I shall now try to retrieve mine from my colleagues.

S.H. Derbyshire

Books received

El Niño — historical and Paleoclimatic aspects of the Southern Oscillation, edited by H.F. Diaz and V. Markgraf (Cambridge University Press, 1992, £40.00) examines for the first time different approaches to reconstructing ENSO based on a variety of proxy sources, ranging from high-resolution environmental indicators such as tree rings etc. to records on the impact of ENSO on fisheries and marine and lacustrine sediments, to a long record of vegetation changes in the southern hemisphere. This book will be of importance to all professional scientists and researchers in climatology, meteorology and the earth and environmental sciences, while graduate students will also find this book a useful reference source. ISBN 0 521 43042 9.

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June storms in the British Isles

From Plymouth Weather Centre

On Wednesday 9 June 1993 parts of south-west Cornwall experienced what has been classified as a 'rare', once in 500 years event. A total of 126.3 mm of rain fell at RNAS Culdrose (03809) between 2300 UTC on the 8th and 1000 UTC on the 9th, more than twice their mean monthly rainfall for June. This in itself was unusual but what constituted the rare event was the 59.1 mm which fell between 0700 and 0800 UTC on the 9th (Fig. 1). The fact that this did not match the record 91.4 mm which fell in an hour at Maidenhead in 1901 was no consolation to the inhabitants of the town of Helston and the village of Porthleven, who bore the brunt of the downpour.

For several days the Met. Office Limited Area Model (LAM) had been indicating that the prevailing hot spell would degenerate into thundery outbreaks some time around 9 June. In this respect it offered good guidance, but what it did not indicate was the rapid development of the storms *in situ* over south-west England overnight.

Unstable medium-level cloud which was advected northwards from Brittany on the evening of 8 June had largely decayed by the time it reach Cornwall, though it did produce some light rain. The first indication of development taking place *in situ* was a small echo south of The Lizard on the Predannack rainfall radar in the early hours of 9 June. The echo expanded quickly accompanied by a marked increase in its intensity; the ascent for Camborne at 09/0000 UTC supported Cb tops to over 40 000 feet. Although only 7 miles north of Culdrose, Camborne escaped relatively lightly as illustrated by their hyetogram (Fig. 2).

As with the Lynmouth flood of August 1952, to which this event has been likened, there is probably little that the authorities could have done to alleviate the flooding. Fortunately in this instance there were no reports of injuries or deaths.

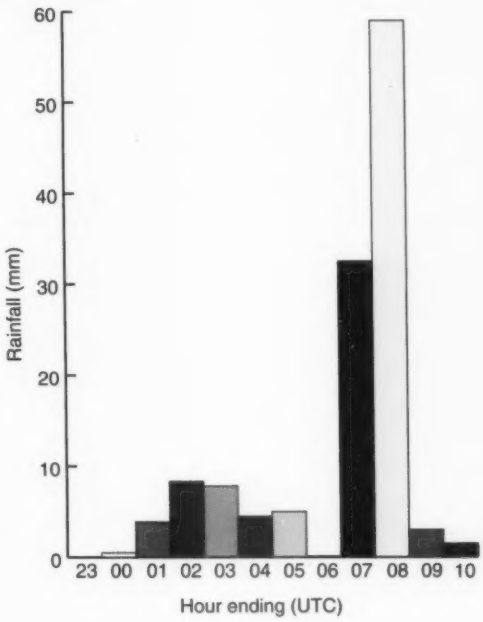


Figure 1. Hourly rainfall at Culdrose on 9 June 1993.

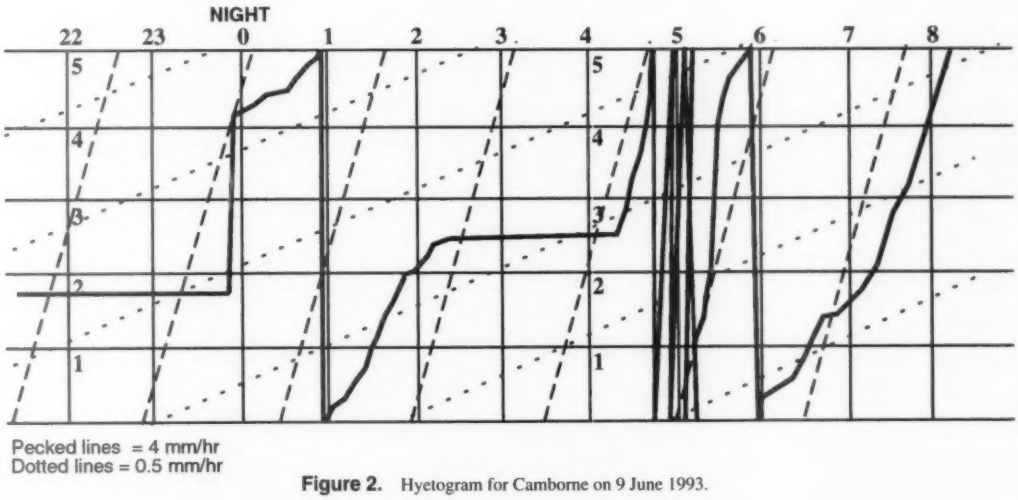


Figure 2. Hyetogram for Camborne on 9 June 1993.

It was reported that the Cornwall Fire Brigade received 80 calls in a short space of time and had to be reinforced by four Royal Navy fire engines from Culdrose. At Porthleven, down the valley from Helston, water poured seawards over the harbour wall instead of the more usual landwards! One newspaper article wrote of a resident being '....waste (*sic*) deep in water....', and likening the scene to something from the Dambusters.

On Friday the 11th and Saturday the 12th the centre of attraction moved further north. In the 24 hours ending 0900 UTC on the Saturday Chivenor (03707), near Barnstaple (Devon), recorded 60.4 mm of rain. Widespread flooding was reported around Bude (Cornwall), where the inshore lifeboat lived up to its title by operating three miles inland!

From Cardiff Weather Centre

A slow-moving upper vortex with areas of very heavy rain and thunderstorms within its circulation drifted east across the United Kingdom on 10 and 11 June 1993.

Rainfall totals were very large in places with flooding in parts of Wales and southern England. During the early evening of the 10th, torrential rain from a thunderstorm in the Llandudno area of North Wales coincided with high tide and swamped the storm water system. Floods up to 5 feet deep occurred in the lower part of the town and around Llandudno Junction. The main A55 expressway was closed due to flooding in the new Conwy road tunnel and there was up to 2 feet of water in Llandudno General Hospital for a time. About 2500 people were displaced by floodwater and rehoused with the help of an emergency social services plan developed after the flooding at Towyn.

A total of 137 mm of rain was recorded in the 24 hours ending midnight on the 10th at Conwy Mussel Tanks just along the coast, and it is thought a significant portion of that total fell in a 2- to 3-hour period during the early evening. Autographic rain-gauges at Colwyn Bay and Betws-y-Coed were reported to have been disabled by the intensity of the rainfall event, so unfortunately no figures are available.

The following day it was the turn of parts of southwest Wales to bear the brunt. Average June rainfall for Aberporth in Dyfed is 56 mm. In the 24 hour periods ending 0900 UTC on 10 and 11 June 1993, the Met. Office at Aberporth recorded 66.0 and 74.6 mm respectively. The previous highest 24-hour rainfall for June was 41.8 mm in 1971. Flooding occurred along the length of the Mwldan, a normally insignificant tributary of the Teifi. Caravans and cars were swept downstream and flooding occurred in many homes in Cardigan itself. The privately run Talyllyn railway had to cancel services for the first time in 42 years after the rain washed debris across the track, washed away an embankment and toppled a large oak tree onto the line.

Cleaning up the flood damage in Wales is expected to cost in excess of £12m, but no lives were lost, thanks to the excellent work of the emergency authorities and timely advice from the Met. Office.

From the Irish Meteorological Service — rainfall records of June 1993

The most notable event was the 24-hour totals in excess of 100 mm which fell in parts of the Dublin–Kildare area on the 11th. This was a most remarkable fall for lowland areas in the east, being over twice the long-term average for the whole of June. The 12-hour rainfalls had a return period of over 100 years and the 24-hour totals a return period of some 250 years at Casement Aerodrome (Baldonnel), which with 109 mm in 24 hours was typical of the worst affected areas. The 24-hour totals at some Dublin–Kildare stations were at their highest ever, exceeding even those of 'Hurricane Charlie' in August 1986 when the Wicklow mountains and much of the Dublin mountains had heavier falls than in this event. Dublin Airport, in spite of having a fall of 93 mm (return period of about 100 years) on the 11th, did have a higher June total in 1958, but 1993 was the wetter June at Casement Aerodrome.

On the 11th the band of the most active rain extended from Sligo to Wexford and was about 120 miles wide. As there were small-scale pockets of intense activity, the totals varied widely even within this band.

While rare in any given location, falls of more than 100 mm in 24 hours at lowland stations have been recorded. The most recent such occurrence in the Dublin city area was in a small-scale thunderstorm which affect the Mount Merrion area, curiously enough on 11th June 1963, when over 180 mm was recorded in 24 hours and over 75 mm fell in an hour. This storm affected an area of only about 8 km^2. The most recent event giving such rainfalls in Ireland occurred in October 1989 when, again on the western side of a slow moving depression, there were falls over 100 mm in parts of Donegal and Mayo.

World weather news — June 1993

If any of you, our readers, has first hand experience of any of the events mentioned below or its like (and survived!), I am sure all the other readers would be interested in the background to the event, how it was forecast and the local population warned.

These notes are based on information provided by the International Forecast Unit in the Central Forecasting Office of the Meteorological Office, Bracknell and press reports. Naturally they are heavily biased towards areas with a good cover of reliable surface observations. Spellings are those used in The Times Atlas.

South America

Antarctic air streaming northwards from the Bellinghausen Sea brought biting cold on the 3rd to southern Chile. Punta Arenas had a maximum temperature of −0.3 °C, which is well below average. This was followed by a night minimum of −4.6 °C which is nearly a degree below the June record. Because this is the coffee growing season, the southern part of Brazil is usually more concerned with frost than rain, however early on the 5th thunderstorms dropped nearly 117 mm in 6 hours on Curitiba, near Sao Paulo.

The east of Argentina was very wet around the 8th with the port of Mar del Plata having 99 mm, nearly half this month's average on the 14th. The 14th was very wet with Junin, Argentina, having 54 mm in only 12 hours up to midday; this is 13 mm more than the monthly average, while across the border in Uruguay Colonia had 72 mm of rain, which is about the average for the whole month..

On the 28th the temperature fell to −5 °C, at La Paz in Bolivia, high up in the Andes, that is 6 °C below normal. (This is not to be confused with La Paz in Mexico mentioned in the next section.)

North America and Gulf of Mexico

The first day of the month saw 'tropical depression No.1' crossing Cuba; this was an ominously early opening to the season and much of Jamaica and Cuba had excessive rain.

The Koahuila region of north-east Mexico started the month with near record temperatures. Low pressure over the south-west USA drew warm air from the Yucatan Peninsula and temperatures rose steadily. At Monclova the temperature reached 43.5 °C on the 3rd. In contrast it was very cold at Las Vegas on the night of the 5/6th; the temperature dropped to 9 °C which equals the lowest ever for June, set back in 1939.

Midland in Texas had an intense thunderstorm on the 9th; in six hours from 1800 they had 78 mm of rain (around twice the average for the whole of the month) while the temperature fell from 32 °C to 18 °C. Severe thunderstorms developed over parts of central USA on the 11th; at Corpus Christi, Texas, 55 mm fell. St Mathews, Kentucky, had 64 mm in only 30 minutes: nearby Lawrenceville had 49 mm fall in one hour. The insured damage put down to hail, tornadoes and flooding was $150m.

During a heavy rainstorm in Atlanta, Georgia, on the 14th a sewer failed under a hotel car park creating a crater 60 m in diameter and very deep: several cars and people were lost, but one of the cars was found three miles away in a storm drain. A few days later there were reports of further tornadoes and flooding from New Mexico to Illinois over the period 17th to 19th leading to about $100m of damage. Further severe storms over the 23rd/24th did another $55m of damage.

Easterly winds got out of the Nevada Desert across the mountains to central California on the 16th. In San Francisco, where the June norm is 21 °C, the temperature rose to 30 °C and then on to 35 °C on the 17th. At the same time hot, thundery weather reached northern parts of the USA, with Chicago having temperatures up to 33 °C, but thunderstorms gave 68 mm of rain, two-thirds of its normal for the month.

Late in the month 'real' storms began when tropical storm *Arlene* developed the Gulf of Mexico and rapidly went aground at Padre Island, Texas, on the 20th; winds were only 35 kn but as one might expect it rained hard. There were totals of up to 375 mm over parts of southern Texas. The same day tropical storm *Beatriz* went ashore on Mexico's Pacific coast around Acapulco. Salina Cruz was fairly typical getting 286 mm of rain in 2 days, compared with the monthly average of 263 mm. Between them the two storms caused flooding and landslides in many parts of Mexico, including the capital: the death toll is thought to have been seven.

Further thunderstorms occurred over Texas on the 25th with 150 mm in one hour reported to have fallen near McGregor; Dallas had 55 mm. These falls caused extensive flooding. On the 29th/30th hail 50–75 mm in diameter was reported in Nebraska and the Dakotas with violent thunderstorms battering Iowa, and rainfalls approaching 170 mm in places: near Chicago there was about 100 mm and the heavy hail in North Dakota destroyed 2500 Airstream trailers gathered for a club outing. In Minnesota, 80% of the corn and soya bean crops were reported seriously damaged by flooding.

The Mexican city of La Paz recorded 48.6 °C on 28 June; this was a new record (see the other La Paz above). Not all that far away Acapulco had heavy rain, 150 mm in just 18 hours.

On the 12th the level of Lake Ontario had fallen enough for the flow down the St Lawrence Seaway to return to normal and allow shipping movements every day of the week. The lake had been raised to about 25 cm above flood level by the winter's rain and snow.

Towards the end of the month flood water coming down the Mississippi reached the second deepest on record at 7 ft above flood stage. The flow was so great that many locks had to be closed, stranding barge traffic from St Louis to St Paul.

Australasia

This information is largely based on that kindly given by the Australian Bureau of Meteorology. The emphasis seems to have been on coldness in Australia this month. Alice Springs did not have a temperature above 12.9 °C during the period from the 2nd to the 8th making it their coldest week in 53 years of records: further north Tennant Creek's maximum of 12.8 °C on the 15th was the lowest in 36 years of data by 1.7 °C. The north-west of Western Australia (WA) had heavy rain on the 8th and 9th giving totals of 75–88 mm and Port Hedland's 62 mm on the 9th beat the 50-year-old record by 7 mm: the flooding damaged roads in the area stranding traffic. In the north-east of the Territory, The Kimberley, had a persistent, cloudy north-westerly from the 10th to the 15th which brought unseasonal widespread rain and abnormally low temperatures, e.g. Halls Creek's maximum of 12.4 °C was its lowest ever by a whole 2 °C in a 45-year record. Before leaving WA we should note that the extreme south-west corner was unusually dry; the 55.7 mm at Manjimup comfortably beats the previous low total of 76.6 mm.

A strong cold outbreak on the weekend of the 11th/12th brought snow and damaging gales to Tasmania, Victoria and the south of South Australia. A wind of 50 kn was measured at Mt Gambier and the A$5m plus damage in Wonthaggi suggested that 67 kn could have been reached there. The heavy snow around Ballarat stopped football matches (*I did not realise that was possible! — Ed.*) and stopped traffic in parts of Tasmania for a time.

Asia

Heavy rain affected south-east China on the 4th and 5th with many places recording nearly 100 mm, about a third of their June normal rainfall. On the 6th the town of Shanwei had recorded a total of 297 mm since the beginning of the month; this is 77 mm more than the usual for the whole month. The heavy rain continued on the 8th when rainfalls of between 130–150 mm were recorded just north of Hong Kong.

There was further heavy rain on the 9th when 137 mm fell at Fogang, 200 miles north of Hong Kong, while on the coast near Hainan Island 145 mm fell. The rain reached Hong Kong on the 11th, where 145 mm fell in 36 hours, about one-third of the June normal. Across the water 71 mm fell on Macau.

During the second week of the month another 393 mm fell on Shanwei. Not far away Shenzhen has an average June rainfall of 269 mm; on the 16th, 254 mm fell and of those 157 fell in 6 hours. The same day in Hong Kong 138 mm fell with considerable local flooding. There were numerous landslides but only one death was reported, this was when a bus station was buried. In the neighbouring Chinese provinces a total of 216 had died as a result of the heavy rains throughout the month and a total of 585 mm of rain had been measured at one site in Guangdong where floods were 2 m deep. Overall more than five million were affected by the resulting floods.

Not all the heavy Chinese rain was in the south-east, Jingdezhn in Chekiang province had 183 mm of rain in the 24 hours ending on the 19th, a mixture of rain and thunderstorms gave one of the highest daily totals they have ever had, about three-quarters of the whole month's rainfall. Further large rainfalls were recorded on the 27th in the province of Szechwan; rainfalls of the order of 150 mm were noted at Zhanjiang; on the Leichou peninsula 114 mm fell as typhoon Koryn passed just south of Hong Kong where several were injured by flying debris and transport by land sea and air was severely disrupted. Meanwhile Shenwei had another 112 mm, making the total for the month 802 mm. At Qinzhou on the Gulf of Tongkin there was 288 mm in only 24 hours (the June average in 215 mm).

Up in north-east China there was a heatwave; on the 19th there were many cities with temperatures of 36 °C and above.

Strong winds and high seas around the Korean port of Busan on the first few days drove many vessels aground, some remaining fast into October.

A depression over the Sea of Japan brought heavy rain to parts of North Korea and northern Japan early in the month. At Chongjin there was a fall of 160 mm up to the 3rd and at Miyako, on the coast of Honshu, there was 125 mm, with 54 mm on the Island of Hokkaido.

The Island of Sulawesi was very wet over the night of the 6/7th when the east coast town of Kendari received 126 mm of rain. They would normally expect it to take 12 days rain to reach 194 mm: there was flooding.

Mount Unzen (near Shimabar, Japan) resumed eruptions on the 22nd; the ash output is of no direct meteorological consequence, but if mixed with significant rainfall, damaging lahars are to be expected (see April notes). On the 23rd the city of Nagasaki in the south of Japan had a lot of rain, 129 mm in all, and this was not unrepresentative of the area.

On the 21st tropical storm Koryn started cruising through the Caroline Islands and the Island of Truk collected 85 mm in just 6 hours while the winds blew around 35–40 kn. Koryn reached super-typhoon status for a while on the 24th when sustained winds of 130 kn, gusting to about 160 kn were diagnosed: the central pressure down to about 905 hPa at this time. Koryn crossed the Philippines on the 26th causing most damage on Luzon. Maximum winds of about 100 kn were accompanied by 100 mm of rain in many places (Sangley Point, Manila Bay, was the wettest with 165 mm). Flood water reached a depth of 3 m in parts of Manila and five were killed in Baguio. The lahars down the slopes of Mount

Pinatubo were anticipated and no-one was caught by them. Next day the captain and three crew of the 9000-tonne freighter *Lian Gang* were drowned when she sank 70 miles south of Hong Kong when her cargo shifted during an encounter with the typhoon.

Flooding of a different type was reported from the eastern side of the Urals. There, sometime during the month heavy rain combined with the thaw. Twelve are believed killed and a hundred missing and much damage caused near the town of Serov.

Indian Subcontinent

Sketchy reports of 27 killed by flash flooding in northern parts of Afghanistan emerged about the 11th: it was not made clear when this happened. More certain though was the catastrophe that happened during the night of the 14th/15th when heavy rain caused a landslide in part of Kabul that buried at least 115 under tons of mud and debris.

Ahead of the monsoon temperatures got higher and higher and in the Indus Valley in eastern Pakistan a temperature of 50.3 °C was recorded on the 7th and nearby at Bikaner a record 52.7 °C. Further south the monsoon was arriving with a vengeance with 207 mm of rain at Calicut on the 7th. Their total for the month at this stage was 420 mm which is half the month's average. Over in Bangladesh the monsoon rain dropped 150 mm at Tezpur in the Brahmaputra Valley.

Heavy monsoon rains had been causing flooding in north-east India and spread to Kerala on the 11th swamping huge areas of farmland. Floods cut off Tripura and parts of Assam. In adjoining Bangladesh at least 220 are believed drowned and millions were marooned by the rising waters. The submerging of a 27-mile stretch of railway line compounded the problems caused by the cutting of road links some days earlier: a service was restored on the 21st. On the 20th there was a report that one gauge had collected another 200 mm of rain.

Just south of Bombay, rainfall of 196 mm on the 15th raised the total for the week to 480 mm. Surat, 120 miles north of Bombay, also got rather more monsoon rain than usual; 212 mm fell in one day on the 24th. This compares with the average for the month of 218 mm.

Some old Met. Office hands will be interested to read that Gan in the Maldives had had 976 mm up to the 22nd, which is about three times the average.

Africa (except the Mediterranean coast)

The area around Mount Kilimanjaro in Tanzania had unusual dry season weather on the 4th. At Moshi, near the mountain, normal rainfall is 26 mm. They got 99 mm; this easily beats the previous June record of 38 mm in 24 hours. Not far away Nairobi had a fair amount of rain at the beginning of the month, the average is about 32 mm but in the two days up to the morning of the 6th there had been 37 mm.

It was very hot in Mali on 7th where the town of Kidal set a new June record with 46.5 °C. The 15th of June brought some very high temperatures to Sudan where 46.2 °C at Atbara was almost a new record.

By the 22nd summer rains were well established over west Africa with large rainfalls in Ghana, where 168 mm fell at Takoradi. Nearby in Benin 48 mm fell in 12 hours on the 21st and on the southern border of the central African Republic 134 mm fell on the 21st at Mobaye. However the most notable rainfall probably was at Tahoua in southern Niger, on the edges of the Sahara. Here 97 mm fell on the 21st; the previous June record for 24-hour fall was 68 mm and the monthly average is only 56 mm.

Algeria's town of In Salah had very high temperatures throughout the last half of June and on the 25th the day maximum was 47.6 °C. With winds blowing at around 30 kn the night minimum temperature was only 38.3 °C; however with the strong sandy wind the relative humidity was only a few per cent.

A combination of unusual rains in the east, and political problems, has allowed the desert locust unimpeded growth in Somalia and during the month the FAO estimated that four swarms were flying south from an area of 23 000 m^2.

The South African Weather Bureau reported that it had been an unremarkable month down there although there was a wide range of conditions. While much of the north was seasonably dry, Ceres near Cape Town managed 99.7 mm in one day. The hot spot was Mtunzini in northern Natal with 33.8 °C to contrast with Buffelsfontein's night minimum of −9.5 °C. On the 11th a deep low brought coastal gales to disrupt fishing, and the active cold front gave heavy rain around the Cape and along the south coast. This was followed by bitterly cold weather which gave heavy snow on the southern Drakensberg — De Aar in the Upper Karoo having its first snow for 10 years.

Europe, North Africa and Arabia

Early on the 6th heavy rain affected much of central Spain with Toledo collecting near 60 mm of rain, compared with a monthly average of only 25. Madrid also had a lot of rain with 29 mm falling in 12 hours about equal to the whole of the month's rainfall.

Something of a heatwave affected England mid-month with temperatures near 30 °C which was enough to reveal that expansion gaps on some sections of motorway were insufficient as they buckled in the heat: elsewhere extra staff were employed to cope with the demand for ice cream.

Very heavy rain fell from thunderstorms over the south-west of the United Kingdom on the 10th and 11th causing serious local flooding. Three were reported drowned as a result of flooding rivers and two died at sea in boating accidents. About the same time storms were affecting eastern Ireland where three were drowned near Dublin in the heaviest rain for seven years: at one stage all roads to the airport were cut and rail services disrupted. Casement Airport collected 103 mm in 30 hours

to the morning of the 12th. Because May was very wet flooding was widespread as numerous rivers overflowed. (*These events are reported separately elsewhere in this issue.*)

Some Alpine storms hit Lakes Maggiore and Lugano areas during the 11–12th; Locarno had 91 mm and Lugano 60 mm (about one-third of the June average). Meanwhile in north-east Germany near Berlin one town collected 109 mm in 2 days of thunderstorms. This is 46 mm more than the June average.

Spain's Costa Brava had a surprise on 23rd when heavy thundery showers broke out; Gerona had 45 mm of rain, the sort of total normally expected to accumulate in the whole of the month. On the same day it was very hot at the other end of the Mediterranean, Damascus had its hottest June day on record with 39.6 °C and in Turkey Izmir's 39.7 °C was nearly 2° above the previous record.

Antarctica

Light winds and clear winter skies brought a bitterly cold 5 days to Vostok in the Antarctic when on the 17th the minimum temperature was minus 71.9 °C. This is somewhat warmer than it had been on the 15th when the minimum was minus 77.3 °C. It was cold for mid-winter for the Americans at Amundsen–Scott; night(?!) minima are normally around -61 °C but on the 23rd the temperature got down to −73 °C, close to the record; next day it was down to −75.3 °C.

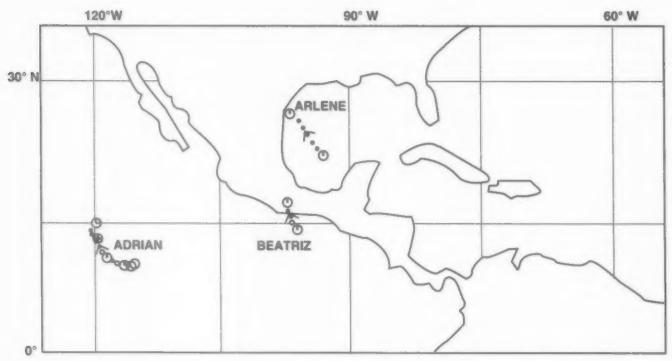
June tropical storms

This is a list of tropical storms, cyclones, typhoons and hurricanes active during June 1993. The dates are those of first detection and date of falling out of the category through dissipation or becoming extratropical. The last column gives the maximum sustained wind in the storm during this month. The maps show 0000 UTC positions: for these I must thank Julian Heming and Susan Coulter of the Data Monitoring group of the Central Forecasting Office.

No	Name	Basin	Start	End	Max. (kn)
1	Adrian	NEP	15/06	19/06	75
2	Koryn	NWP	15/06	28/06	130
3	Beatriz	NEP	18/06	20/06	50
4	Arlene	NAT	18/06	21/06	35

Basin code: N — northern hemisphere; S — southern hemisphere; A — Atlantic; EP — east Pacific; WP — west Pacific: I — Indian Ocean; WI — west Indian Ocean; AUS — Australasia.

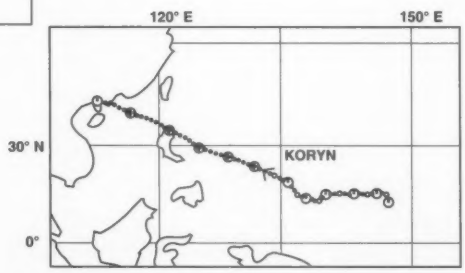
Super Typhoon Koryn affected the Philippines, Hong Kong and Korea, see under Asia above.
Tropical storm Beatriz affected western Mexico; Arlene affected eastern Mexico and Texas.



Key:

◯ 30–60 kn

⊕ 60–120 kn



Your Editorial Board announces that the Meteorological Office Board has decided that the publication of the *Meteorological Magazine* will cease with the issue for December 1993.

As one of the leading European establishments for research into meteorology our publications should be subject to external peer review: this is already the case for much Meteorological Office work. The publication of a new international and European quarterly journal by the Royal Meteorological Society (to be called *Meteorological Applications*) is expected to provide a suitable vehicle for the kind of articles that now appear in *Met Mag*, namely on research, practice, measurements, reviews, applications of meteorology, book reviews, etc.

The December 1993 issue of *The Meteorological Magazine* will be a bumper one of about 40 pages celebrating the Magazine's contribution to the development and dissemination of meteorological knowledge. It will contain a selection of highlights from 1866 up to around 1986.

The United Kingdom Meteorological Office (UKMO) Annual Scientific and Technical Review

This Review describes the major developments in science and technology within the UKMO over the year and is produced as part of the Meteorological Office Annual Report and becomes available in July each year. If you wish to be put on the mailing list please write to:

The News Desk,
Publications (room 709),
Meteorological Office,
London Road,
Bracknell,
Berks
RG12 2SZ.

Informal communications

The UKMO has instituted an in-house periodical for informal and rapid dissemination of the latest relevant science and technology news to its staff and outside collaborators. Most contributions come from UKMO staff, but offers of material from outside will be welcome — though there is no guarantee of publication.

Back numbers: Full-size reprints of Vols 1–75 (1866–1940) are available from Johnson Reprint Co. Ltd., 24–28 Oval Road, London NW1 7DX. Complete volumes of *Meteorological Magazine* commencing with volume 54 are available on microfilm from University Microfilms International, 18 Bedford Row, London WC1R 4EJ. Information on microfiche issues is available from Kraus Microfiche, Rte 100, Milwood, NY 10546, USA.

September 1993

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Editorial Board: R.J. Allam, N. Wood, W.H. Moores, J. Gloster, C. Nicholass, G. Lupton, F.R. Hayes

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